

Exhibit 15



The Peregrine Corporation

Specialists in Defense Dynamics

July 31, 2023

Daniel L. Schmutter, Esq.
Hartman & Winnicki, P.C.
74 Passaic Street
Ridgewood, NJ 07450

Re.: Supplementary Letter - Ellman, et al. v. Platkin, et al., and Ass'n of New Jersey Rifle & Pistol Clubs, Inc. et al. v. Platkin, et al.

Dear Attorney Schmutter:

I am writing to provide a brief supplement to my initial report of June 15, 2023 ("Initial Report") and my reply report of July 17, 2023 ("Reply Report") in the above-referenced cases.

In my Reply Report, I discussed the ballistics of the Brown Bess musket, which was the shoulder weapon most commonly used by both the British and the American ("Continental") troops in the American Revolution. See Reply Report, pages 7-9.

After submitting my Reply Report, I received additional information supporting the facts and opinions provided in that report. Information I received included the following:

The Lead Historic Weapons Supervisor at the Valley Forge National Historical Park (U.S. National Park Service) sent me several articles providing research on the ballistics of 18th Century flintlock muskets, including the Brown Bess. The most relevant of these articles are *A Detailed Study of the Effectiveness and Capabilities of 18th Century Musketry on the Battlefield*, N.A. Roberts, J.W. Brown, B. Hammett, and P.D.F. Kingston, Koninklijke Brill NV, Leiden, 2008; *Colonial Era Firearm Bullet Performance: A Live Fire Experimental Study for Archaeological Interpretations*, D. D. Scott, J. Bohy, N. Boor, C. Haecker, W. Rose and P. Severts (2017); and *Shooting the Past: Colonial & Revolutionary War Firearm Live Fire Experiments & Spherical Ball Performance*, J. Bohy, American Society of Arms Collectors Bulletin 118:44-46 et seq. These articles are provided herewith as Exhibits 1, 2 and 3, respectively.

One of the articles (Scott, *supra*, at 20, 23 ff.) made reference to ballistic testing of the Brown Bess musket by a nationally-known firearms and ballistics expert, Lucien ("Luke") Haag. Among other things, Luke Haag has been prominent in AFTE (the Association of Firearms and Toolmark Examiners), and is the author of one of the leading texts on shooting scene reconstruction. After reading the reference to Haag's work with the Brown Bess, I called him

and discussed Brown Bess ballistics. Following our phone conversation, Mr. Haag emailed me several PowerPoint presentations he had previously prepared on his testing of muzzleloader ballistics. A copy of his PowerPoint, *March 7, 2015 Tests at Ben Avery Range, .72 Cal. "Brown Bess,"* Slides and Calculations by Luke Haag, Forensic Science Services, Inc., presenting the test results for the Brown Bess musket is attached as Exhibit 4.

Finally, before preparing my Reply Report I had spoken by telephone with Mr. Harold Coleman of the National Muzzle Loading Rifle Association. He offered to speak with several of his association's members who shoot Brown Bess muskets, regarding that firearm's ballistics. After submitting my Reply Report, I heard from Mr. Coleman that, based on information provided to him by Brown Bess shooters, velocities with round lead musket balls could easily range from about 800 to 1200 feet per second. The lower velocities would be achieved when no wadding was wrapped around the musket ball, while the higher velocities would be reached when the cartridge paper was left wrapped around the ball as it was rammed down the bore in loading, so that the paper served to make a better gas seal when the gun was fired. Mr. Coleman said that members would be glad to provide specific velocity results of chronograph testing if requested.

Based on the above, the modern ammunition and projectile that provides the closest comparison to the .69 caliber, 494-grain lead round ball fired from the Brown Bess musket at velocities averaging about 1,000 feet per second during the Revolutionary War is the 12-gauge rifled slug. Widely used by law enforcement agencies, by hunters of deer and black bear, and by hunting and fishing guides for protection against grizzlies and other large, dangerous animals, 12-gauge rifled slugs are .729 caliber, and weigh one ounce (437.5 grains). When fired from the shorter barreled shotguns typically used by police and big game hunters, 12-gauge rifled slugs, in either standard loading or in the popular "low recoil" versions, often produce muzzle velocities in the range of 1,150 to 1,300 feet per second. Thus, the 12-gauge rifled slug is similar in caliber to a Brown Bess musket ball, slightly lighter in weight, and slightly faster in muzzle velocity. The practical effective range of a 12-gauge rifled slug is about 100 yards, about the same as the practical effective range of the Brown Bess musket. There is general agreement among firearms users that within its effective range, the 12-gauge rifled slug is devastatingly effective as a law enforcement or self-defense round, or for use in shooting animals the size of deer or bear. A photograph comparing the .69 caliber lead musket ball used in the Brown Bess to the 12-gauge rifled slug is attached as Exhibit 5.

Of particular interest are the observations of the author of the Roberts, et al. article, *supra*, at pages 15-16, regarding the ballistic gelatin testing of .69 caliber Brown Bess musket balls at 150 and 75 yards, representative of likely battlefield musket engagement distances. Regarding the 150-yard effect, the authors noted:

The maximum permanent cavitation was around 40 mm. It is assessed that this level of damage to the ballistic gelatine block represents a catastrophic effect on a human torso at the likely maximum distance of engagement, assuming a strike to the torso.

Regarding the 75-yard effect of the Brown Bess musket ball, the authors noted:

The temporary cavitation is much greater at 75 yds compared to 150 yds, meaning that considerably more damage would have Occurred, that would almost definitely have been fatal.

Attached as Exhibit 6 is a photograph showing a .69 caliber lead musket ball and various military and sporting cartridges in use from the late 1880's to the present time, compared to the .223/5.56mm AR-15 cartridge. From left to right, the munitions in Exhibit 6 are:

- 1) .69 caliber lead musket ball, as used in Brown Bess muskets in the Revolutionary War;
- 2) .303 British, introduced in 1888 and used by British, Canadian and Australian military forces in World Wars I and II;
- 3) .30-40 Krag, used in the U.S. military Krag-Jorgensen (M1892 Springfield) rifle, adopted by our military in 1892, used in the Spanish-American War, and until 1903;
- 4) .30-30 Winchester, first offered in 1895 in the Model 1894 Winchester lever-action rifle, and a popular cartridge for hunting deer-sized game to this day;
- 5) .30-06 Springfield, developed in 1906, used as the primary U.S. military cartridge in World Wars I and II and the Korean War, and a popular big-game hunting cartridge to this day;
- 6) 7.62x39mm cartridge, developed in 1947 for the AK-47 rifle;
- 7) 7.62mm NATO, developed from the commercial .308 Winchester in the early 1950's and used in the M14 rifle and M60 machine gun in Vietnam, and a popular hunting, law enforcement, and competitive target shooting cartridge today; and
- 8) The AR-15 cartridge, developed as the .223 Remington in the 1960's for civilian use, and slightly modified to become our U.S. military rifle cartridge as the 5.56mm NATO in the late 1960's through early 1970's.

I note that after over 50 years of attempting to improve the 5.56mm NATO's shortcomings in power, range, and penetration, the U.S. military is now transitioning to a 6.8mm cartridge for its infantry rifles and squad automatic weapons. The new 6.8mm cartridge will have a larger-caliber projectile that weighs roughly twice as much as the 5.56mm bullet, for improved range, penetration, and energy.

Note of the information I have received after submitting my Reply Report serves to change my opinions expressed in that report, or in my Initial Report of June 15, 2023. The newly-received information simply further supports and confirms my previous opinions.

All of the facts and opinions I have expressed in this letter are accurate to a reasonable degree of professional certainty in my fields of expertise.

Very truly yours,

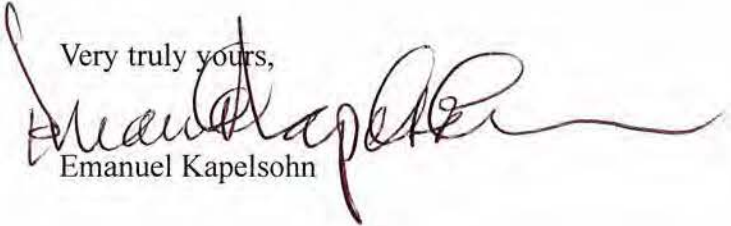

Emanuel Kapelsohn

EXHIBIT 1

A DETAILED STUDY OF THE EFFECTIVENESS AND CAPABILITIES OF 18TH CENTURY MUSKETRY ON THE BATTLEFIELD

N A ROBERTS, J W BROWN, B HAMMETT & P D F KINGSTON

ABSTRACT

During the mid 18th century, the standard British Army issue weapon was the Brown Bess Musket. There are various accounts of the performance of this early form of firearm and its tactical deployment (e.g. Hanger 1816). Using a technical replica of the Brown Bess, range trials and computer modelling have been used to assess the weapon's capabilities and likely performance. The research found the Brown Bess musket to be a lethal weapon at the ranges at which enemy was commonly engaged, so long as it was accurate enough to hit the target. A single shot fired at 150 yards could penetrate at least two soldiers, even if bone were hit. The armour of the day (shields of wood, leather and sometimes steel, and the layers of woollen clothing) was easily pierced by the shot. The shot was found to readily deform on impact with metal targets. The maximum range could extend to around 1200m, with 202m reached when fired horizontally.

Introduction

Background

The nature of warfare is always dictated by the principle weapon systems available at the time. In the 18th century, the principle weapon system used by the British infantry was a smooth bore musket. The weapon was employed in platoon-sized groupings, which fired volleys of lead shot in the direction of the enemy (shots were not aimed). The musketeers would form a static location in front of an advancing enemy, or fire while advancing until close enough for hand-to-hand combat. It is clear that the performance of the musket would have a direct influence on the tactics and the outcome of the battle. However, historical sources provide many conflicting accounts of the capability, performance and reliability of this weapon system (Hughes 1974). Perhaps the most often quoted reference comes from the hand of Colonel George Hanger who saw service with the British Army during the American Revolution:

'A soldier's musket, if not exceedingly ill-bored, as many are, will strike a figure of a man at 80 yards; it may even at a hundred; but a soldier must be very unfortunate indeed who shall be wounded by a common musket at 150 yards, providing his antagonist aims at him; and, as to firing at a man at 200 yards with a common musket, you may as

well fire at the moon and have the same hope of hitting him. I do maintain and I will prove, whenever called on, that no man was ever killed at 200 yards, by a common musket, by the person who aimed at him (1816: 205).'

Aim

The aim of this research project was to conduct a thorough ballistic examination and provide a performance assessment of an 18th century musket. In recent years, there has been an increasing interest in the examination of the performance and capabilities of historic firearms, including artillery, through experimentation and replication (e.g. MacPherson 1994; Pollard & Oliver 2003; for a detailed study of cannon-fired case shot, see: Allsop & Foard 2007). This interest has also been reflected through the activities of hobbyist black powder shooters, most particularly in the USA (e.g. James n.d.). The project focused on the investigation of the Brown Bess Musket as used by the British Infantry at the Battle of Culloden on 5 April 1746. This battle is of particular interest as archaeological investigations have resulted in the recovery of numerous lead projectiles including musket balls and the present project received support and encouragement from Dr Tony Pollard, the archaeologist leading that work. This weapon was widely popular, and remained in use without major modifications until the 1800s, when rifles eventually made smooth bore muskets obsolete.

Approaching the problem

Due to the value, scarcity and deterioration of original Brown Bess Muskets, the firing of a technical replica Brown Bess was the most appropriate method of analysing the ballistic properties. Using a technical replica, with similar bore and barrel dimensions to the original, would ensure more consistent experiments could be carried out.

Range trials were conducted with the aim of replicating the known performance (particularly muzzle velocity) of the Brown Bess. Computer modelling was used concurrently to maximise the information obtained from each trial. The conditions derived from these trials enabled the setting up of accurate and realistic tests examining the wound effects the weapon could inflict in different tactical situations (such as closer ranges and differing amours). The effect of impact on the lead shot was also examined by using a soft capture box.

The Brown Bess

The historical context for this research project was the Battle of Culloden, where the British Infantry used the Brown Bess Musket. Existing documen-

tary evidence of the performance of the Brown Bess from the majority of sources tends to provide a historical, rather than technical perspective. This project used technical methods to address the accuracy and veracity of these historical records. It is known that the weapon weighed around 10 lbs 8 oz (4.7 kg), had a 46-inch length barrel with a 0.75 inch (1.87 cm) bore diameter. The shot fired was 14 bore lead, contained in a cartridge made of hemp and cotton paper.

Description of the Brown Bess Musket

Capability

It should be borne in mind that the capability of the small arms system is not merely a function of the capability of the weapon. The human-weapon interface plays an important role, resulting in fluctuations in a soldier's performance depending on his size, physical state (tired, cold, wet), and mental state (scared if in battle). His weapon handling under these conditions will be improved by good training, which should go some way to minimise the effects of these conditions. The investigation of these variables falls out of the scope of this project, and a rigid mounting for the weapon was used to eliminate human variation. This allowed the investigation of purely the ballistic capabilities of the Brown Bess, operated at similar ranges to those fired during the Battle of Culloden (Pollard 2005).

Ammunition

The ammunition cartridges were made of paper containing one lead shot and a quantity of gunpowder, and tied off with twine. The concept of using cartridges was introduced to make firing the weapon easier whilst ensuring a more consistent amount of gunpowder. It also assisted in keeping the powder dry and reduced windage (the small gap between the lead shot and the calibre of the barrel) as the paper also served as wadding (see below).

Propellant

Little evidence exists as to the exact scientific details of the gunpowder used, but it is believed to be a mixture of saltpetre, charcoal and sulphur in the ratio of 75:15:10, and of mixed grain size. The amount in each cartridge was between 5 and 6 drams (8.89 to 10.66 g), of which 10 grains (0.65 g) was used for priming (Harding 1999: 105).

Cartridges

The lead shots used in the cartridges were cast in moulds and quenched in water. A small burr was left from where the lead was poured into the

mould. Paper used to make cartridges in the 18th century differs from today's paper, as it was made from a linen or cotton texture, like fine rags. The lead shot was placed at the bottom corner of the paper, which was then folded over it. The cartridge was rolled by using a wooden rolling rod (0.65 in diameter) to form a cavity for gunpowder. The end with the shot was tied off with twine, and the gunpowder poured in through the open end.

Operation

Musketeers would bite off the end of the cartridge, pour a small amount of gunpowder into the flintlock pan, with the remainder being poured down the barrel. The shot was then rammed down the barrel with a rod and the cartridge paper became wadding. This protected the shot during ramming, held it in place between loading and firing, and provided forward obturation during shot travel down the barrel. On pulling the trigger, a flintlock produced a flash that ignited the powder in the pan, burning through a tiny hole into the chamber. This would then ignite the gunpowder confined inside, producing rapidly expanding hot gases that forced the lead shot and the wadding out of the barrel. In this simple explanation of the firing procedure, it is already obvious how much room for variation there would be, potentially affecting the ballistic performance.

Muzzle Velocity

When examining the performance of a small arms weapon, muzzle velocity is the conventional measurement taken. Unfortunately, there are no records of the muzzle velocities of the Brown Bess from the mid 18th century, and not many experiments appear to have been conducted in that era. However, Mordecai (1845) conducted a series of experiments in the mid-19th century which can be extrapolated to estimate the likely muzzle velocity of the Brown Bess. The gunpowders he used were mainly from the US, but the figures obtained generally corroborate the data for the few British powders that he tested. Robins also conducted research on ballistics, published in 1742, which along with Mordecai's work, show that muzzle velocities of 1500 feet per second (fps) or 457.2 metres per second (m/s) were being obtained from muskets (Harding 1999: 371). The velocity of sound in air is 1100 fps, showing that the projectile travelled at supersonic speeds.

Until manufacturing processes were improved in the late 18th century, gunpowder was extremely variable in quality (Nonte 1969: 191). There were numerous reasons for this, including: inconsistencies in the charcoal produced by charring timber in stacks; the type and age of wood used; impurities in the saltpetre and sulphur; and method of formulation and mixing. When in

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use, this resulted in unpredictable muzzle velocities on firing the weapon. The tactical manner of using soldiers in long lines firing in the general direction of the enemy, however, meant that variations in muzzle velocity did not matter greatly for battlefield effectiveness.

*The Battle of Culloden**Background*

The Battle of Culloden took place on the afternoon of 6 April 1746. On one side were 5,000 Jacobite troops (including Highlanders, Lowlanders, some French and a few Irish), equipped with muskets, pikes, axes and other hand-held weapons, commanded by clan chiefs loyal to Bonnie Prince Charlie. Their enemy numbered around 9,000 Government troops, well equipped with the Brown Bess musket. The Jacobites were tired after an unsuccessful attempt at a surprise attack the previous night, which had failed due to navigational errors. At the start of the battle, the government lines stood around 500 m away, separated by ground entirely unsuitable for the traditional Highland charge (victory at Killiecrankie in 1689 resulted from Jacobites charging down hill—the ground at Culloden was variably wet and despite various topographic variations was far more level in character).

As a precursor, both sides engaged with artillery, first in counter-battery fire, with the Government guns then switching to the Jacobite infantry once the artillery had been knocked out. When the order to charge was given the message was not passed properly, and the Jacobite advance became dislocated. While charging to engage in hand to hand fighting, the Jacobites suffered further attrition from heavy volley fire from the Brown Bess Muskets of the Government troops. They did break through the Government lines in some places, but were defeated by depth in the Government lines. A disorderly retreat followed, and combined with successful flanking manoeuvres by the government cavalry, the Jacobites were routed in less than an hour. Government losses were just 350 men dead and injured compared with at least 1,200 Jacobites dead.

Tactics

The Government troops employed volley fire from their muskets. This broke down charges, and reduced numbers of enemy able to engage in hand to hand fighting. Ranges varied from around 150 yds down to point blank range. The soldiers were told not to aim, but simply hold the weapon horizontally and fire. Although firing by platoon was normal by the time of the battle this was dispensed with in favour of volley fire by battalions deployed in triple

lines—thought by General Hawley as the only way to break a Jacobite charge. The front rank, probably kneeling, kept their bayonets charged and did not reload after the first volley, thus providing a protective hedge of bayonets in front of the two firing ranks (Reid, in press).

Historical Sources

Some sources would suggest that the Brown Bess did not perform well ballistically, proposing that shot penetration of the body was rare, and could be prevented by wet clothing or shields. Contradicting this, there was also circumstantial evidence that a single shot could penetrate two men standing one behind the other. There are also doubts about accuracy over engagement ranges, and the wounding characteristics that were produced:

Accuracy of the Brown Bess was, as with other muskets, low. The effective range is often quoted as 100 yards (91.4 m). The combination of large calibre of the projectile, the heavy weight of its lead construction, and its unstable aerodynamic shape (a round ball marred by hand casting) contributed to its low effective range (historical plaque at battle site).

It is my conclusion that effective musket fire was not possible at ranges above 150 yards. This echoes the sentiment of some contemporary writers. Furthermore given the poor field conditions and the little or no target practice that the conscripts had, really effective fire could probably not be delivered at ranges above 100 to 150 yards (Willegall, 1999: 9).

There has also been a modern fascination with the supposed high recoil resulting from firing a Brown Bess. It is believed by some that government soldiers lessened the painful effects of this by reducing the amount of powder rammed down the barrel. This would reduce the muzzle velocity of the shot, and so affect the range, accuracy and penetration of the shot. Finally, further to a recent find of interestingly deformed shots from the site of Culloden (Pollard 2005), trials were conducted to simulate the lead shot colliding with metal edges, such as sword blades or belt buckles.

Replicating the Brown Bess

Weapon Selection

The aim of this project was to, as realistically as possible, analyse the ballistic properties of the 18th century Brown Bess musket. An ideal way to have done this would have been to acquire, test fire, and measure the performance of an actual Brown Bess musket. However, while considering the use of an original or replica musket, a number of practical issues became immediately apparent.

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Firstly, original 18th century Brown Bess muskets are now historical artefacts, and could be considered more works of art than functioning weapons. Even though an original musket could be obtained, preserving the condition of the weapon could not be guaranteed with the range of conditions under which it would have been fired. Furthermore, the material integrity of a 250 year old weapon would have posed a potential safety hazard to personnel and property at the experimental range.

Secondly, consideration was given to using a replica Brown Bess, which would at least solve the question of material integrity. However, given the range setup, properly mounting the weapon for repeatable firings proved to be unworkable without causing damage to the weapon. Limited finance was also a limiting factor for this option. It was therefore decided that a technical replica musket, which matched the pertinent specifications of the Brown Bess, would be designed, fabricated, and used during the project's experimental firings.

Design and Operation of the Technical Replica Brown Bess

The design of the technical replica Brown Bess was kept very simple. A 42 in (1066.8 mm) long EN 24 steel tube was used to replicate the barrel. The inner diameter of the tube was 19 mm, which closely matched the Brown Bess's 0.75 calibre. The tube's wall thickness was 3 mm thicker than the original Brown Bess's barrel. This was chosen to ensure safety on the range, whilst having a negligible effect on the ballistics of the weapon. It allowed varying amounts of gunpowder to be used knowing that the barrel would not fail under the high pressures.

The chamber end of the barrel was threaded to accept an adapter used to fit the barrel in the firing mount found at the Small Arms Experimental Range (SAER). An off-axis cavity was drilled into the side of the adapter to replicate the musket's flashpan. A 2 mm touch-hole was drilled through this cavity into the chamber of the barrel. In this way, gunpowder initiated in the cavity would ignite gunpowder in the chamber via the touch-hole causing the replica to function in the same manner as the flintlock Brown Bess. The gunpowder in the flashpan was initiated remotely using a Vulcan Fusehead (an electric matchhead), 20 ft of copper wire and a 9 V battery.

The replica Brown Bess was therefore a series of screw thread applications put together to measure safely the performance of the weapon in a controlled environment. Table 1 shows a summary of specifications for the Brown Bess technical replica.

<i>Property</i>	<i>Details</i>
Calibre	19.05 mm
Barrel Length	1066.8 mm
Shot Diameter	17.53 mm
Touch-Hole Diameter	2 mm
Loading Method	Muzzle Loaded
Firing Method	Electrically
Bore Type	Smooth

Table 1. Brown Bess Technical Replica Specifications

*The Replica Cartridge**Paper*

The paper used for the replica cartridge was obtained from Falkiner Fine Papers of London via their manufacturer, Griffen Mills in the Republic of Ireland, and mirrored as closely as possible that used in the 18th century. The paper type used was called 'Wove', made from a blend of cotton and hemp fibres, cream in colour and weighing 80 g/m² (about 0.004 in in thickness). The cartridge paper was cut to size and rolled as described earlier to incorporate the lead shot, before pouring in the gunpowder. Thin strands of parcel string were used to replicate the twine.

Shot

There was much debate about the purity and density of lead used in the 18th century for the shot. The shot used in this research was cast from pure lead, identical to that used for roofing houses. Using modern day moulds, the shot was cast in the traditional method by the 'Muzzle Loaders Casting Shack' in Clacton on Sea. Research suggests that during the Battle of Culloden in 1746, the Brown Bess fired 14 bore lead shot. The closest obtainable match to this was 0.691 inches in diameter, which was used during the research.

Gunpowder

Gunpowder is not now made to the same standards or using the same process as in the 18th century (Buchanan 1996). The old method involved using a pestle and mortar to incorporate the saltpetre, sulphur and charcoal; a process which would last up to eight hours. This would now contravene modern safety regulations, so it is not possible to replicate this important step.

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Even if it could be attempted, it would be virtually impossible to match all the characteristics of the powder exactly due to the complex nature of gunpowder. Additionally, as mentioned previously, the gunpowder was extremely variable in quality. Therefore, replicating true 18th century gunpowder would involve incorporating a degree of inconsistency.

A partial aim of this project was to assess the ballistic properties of a Brown Bess, it was decided to use modern gunpowder in order to ensure reliability when examining the ballistic effects. Due to lack of records, the specifications of the powder used in the Brown Bess are unknown, although there is circumstantial evidence to suggest that it was of mixed grain sizes. Three modern day gunpowders were obtained: Black powder Type 3A (fine); G12; and blasting powder, with the aim of testing them individually and mixed, in order to find the closest match to 18th century gunpowder. Measuring the muzzle velocity would give an indication of how similar in terms of power each gunpowder was to that used in the 18th century.

Computer Modelling

Internal Ballistics Modelling

The program used to model the internal ballistics of the Brown Bess technical replica was HMSOV, which was created with the Matlab computing language. By inputting the weapon's specifications (and making realistic assumptions where necessary), the program calculated muzzle velocity, peak pressure, and defined a pressure/travel history curve. Three input files were created; one to represent each of the charges used: 7.5 g, 10 g, and 15 g.

Defining the Parameters

An input file was used to define the parameters of the projectile. These parameters included muzzle velocity, projectile mass, shot calibre, angle of elevation, initial height, and coefficient of drag (C_D). Based on the input parameters, the external ballistics modelling program calculated the trajectory. For every metre of range, the program output listed values for total velocity, horizontal and vertical components of velocity, vertical displacement, C_D , Mach number, and elapsed time.

Calculating Muzzle Velocity

Once the likely muzzle velocity of 1500 fps (457.2 m/s) was identified through the use of data from historical sources, it was a simple matter of

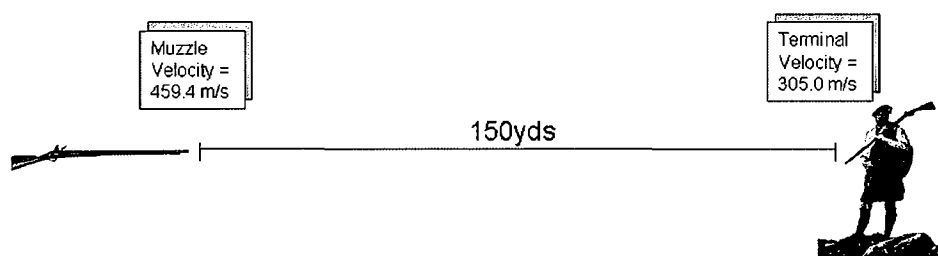


Fig. 1. Terminal Velocity measurement for an historical engagement

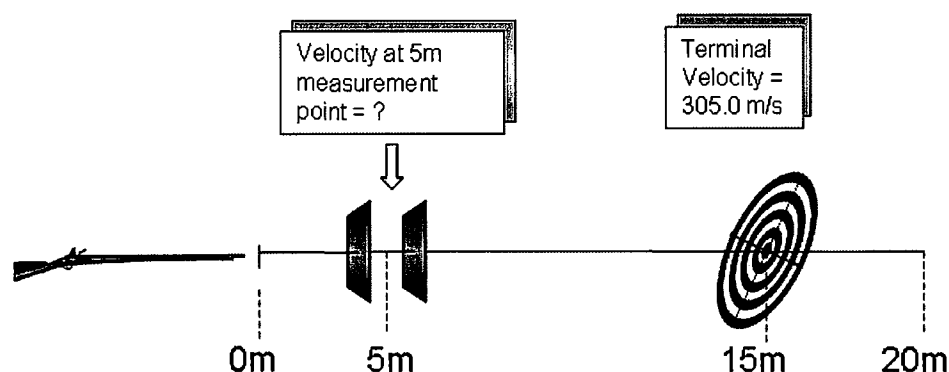


Fig. 2. Range scaling for target at 15 m on a 20 m range

defining parameters for the input file to determine what the terminal velocity would be at a given target range. Normal engagement ranges during the 18th century have been quoted as being 150 yards (137 m). The output data found the terminal velocity at a 137 m target would be approximately 304 m/s. It should also be noted that when fired from a height of 1.5 m (roughly shoulder height), at 137 m the shot would have dropped to approximately 0.9 m above the ground. Also, if no target were hit, the shot would travel until it hit the ground at approximately 201 m.

The external ballistics modelling program also aided in the design of the terminal ballistics experiments. For simulating a 150 yd engagement, and with a muzzle velocity of 459.4 m/s from range data, the computer model predicted a terminal velocity of 305 m/s, as depicted in Fig 1.

To simulate this engagement on the 20 m firing range (with the target located at 15 m), it was required to know what velocity needed to be registered at the measuring point 5 m from the barrel, as shown in Fig 2. The 127 m entry in the output file (137 m-10 m) indicated that the velocity at that point will be 313 m/s. Thus, by measuring a velocity close to 313 m/s

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on the range, it could be confidently estimated that the terminal velocity would be near the expected value of 305 m/s.

Maximum Range

As the replica musket could only be fired using the clamp at the 20 m range, maximum range could not be measured practically. Ballistic modelling was therefore also employed to predict the maximum range achievable, and at what angle of elevation this would occur. By inputting the relevant parameters, it was found that around 1,200 m could be reached when firing at 35° of elevation, compared to 202 m when firing horizontally.

*Ballistic Experiments**Experimental set up*

All of the trials were conducted at the Cranfield University SAER; an indoor range with a remote firing capability and ability to fire replica barrels. The replica musket was mounted in a clamp which eliminated human based firing variations. Equipment was available for measuring projectile velocity as well as weighing facilities for gunpowder. The cartridges to be fired were pre-made using the method described previously. The replica musket was positioned in a clamp at the end of the 20 m range. Aluminium laminates mounted in stands were used to measure shot velocity.

Preparing the Cartridge

The gunpowder was weighed out at the range and then placed inside the cartridge, with 0.65 g of the total amount weighed separately to be used for priming. The quantity and type of gunpowder used varied depending on which experiment was being conducted. Exact details are described in the methods later in the Chapter. After fixing the replica musket in the stand, the cartridge was loaded into the barrel in the same manner as used in the 18th century: the top of the cartridge paper was bitten or ripped off, and the powder it contained placed into the barrel.

Loading the Cartridge

As the barrel was fixed in the stand, it was not possible to tilt the weapon and pour the powder down the barrel. Instead, a small scoop mounted on a wooden pole was used. The powder was poured onto the scoop, inserted in the barrel and emptied at the chamber end of the barrel. The remainder of

the cartridge was then inserted down the barrel using a ramrod. The paper end went in first in order to act as wadding, with the shot (still wrapped in paper) separated from the gunpowder by this wadding.

Firing the Weapon

The remaining powder (the 0.65 g kept aside for priming) was then poured into the recess created to represent the pan found on a musket. An electric match head was positioned in the pan, ensuring it made contact with the powder. With the weapon prepared, all personnel retreated to another room. The weapon was fired by connecting the wire from the match head to a 9V battery. This caused the match head to burn, igniting the powder in the pan. The flames went through the touchhole to the powder in the chamber, which in turn ignited. The expanding gases provided the force to accelerate the shot down the barrel and towards the target.

Experiment to find Gunpowder equivalent to 18th Century Gunpowder

The aim of this experiment was to trial several modern gunpowders in order to find a composition and amount that achieved the closest match to that used in the 18th century. The intention was to obtain a muzzle velocity of 1500 fps (457.20 m/s), whilst using a quantity of gunpowder as close as possible to that used with the Brown Bess.

Results

A total of 21 firings were conducted using 3 different gunpowders. It was found that the type 3A and G12 both produced similar muzzle velocities, which were higher than that of the coarse Blasting Powder. When 3A and G12 were combined whilst keeping the same total mass, an even higher muzzle velocity was obtained. It was found that using 15 g 3A and G12 in a ratio of 1:3 achieved an average muzzle velocity of 459.4 m/s (1507.2 fps).

The results, shown in table 2, demonstrate the unpredictable and inconsistent performance of a gunpowder fired weapon, particularly noticeable with G12.

Conclusion

During the 18th century, about 10 g of gunpowder was used, achieving a muzzle velocity of around 1500 fps (457.2 m/s). As the modern powder used was not as powerful as that of the 18th century, 457.2 m/s could not be obtained using the same quantity of powder. This was expected as the modern powder was created for a different intended use. However, the most powerful effect was found by mixing 3A and G12, rather than using them

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<i>Firing No.</i>	<i>Amount of Powder (g)</i>				<i>Velocity (m/s)</i>
	<i>3A</i>	<i>G12</i>	<i>Blasting Powder</i>	<i>Total</i>	
1	10			10	314.7
2	10			10	282.2
3	10			10	204.9
4		10		10	130.2
5		10		10	329.3
6		10		10	210.7
7			10	10	138.4
8			10	10	110.7
9			10	10	186.6
10	5	5		10	305.3
11	5	5		10	271.6
12	5	5		10	295.0
13	2.25	7.75		10	336.5
14	2.25	7.75		10	310.0
15	2.25	7.75		10	291.6
16	4.5	13.5		18	448.7
17	4.5	13.5		18	476.7
18	5	15		20	513.9
19	3.75	11.25		15	447.1
20	3.75	11.25		15	473.8
21	3.75	11.25		15	457.2

Table 2. Varying Gunpowder Type and Quantity

individually. 15 g of 3A and G12 mixture in a ratio of 1:3 gave the closest match to the desired effects, producing an average muzzle velocity 459.4 m/s (marginally above 1500 fps). This increased velocity from mixing the powders could be due to the powders having individual pressure/travel curves, which peak at different distances down the barrel. When mixed, the pressure/travel curves are combined, leading to a longer peak pressure (larger area under the graph) and therefore higher muzzle velocity.

Experiment to Synthesise hitting Targets at 75 and 150 yds

Having achieved the muzzle velocity of the 18th century, the amount of gunpowder used then was scaled down to achieve the desired terminal velocities for the future experiments. Given that the SAER range was 20 m long

and the targets positioned at the 15 m point, the ballistic modelling found that to achieve the effect of hitting a target at 150 and 75 yds, muzzle velocities of 313.0 and 379.0 m/s respectively were required. This experiment aimed to find how much powder was needed to obtain these values. Different quantities of the 1:3 mix of 3A/G12 gunpowder were fired using the replica musket, and the quantity varied until the desired muzzle velocities were achieved.

Results

Using the results from the previous experiment, the average muzzle velocity of 312.7 m/s obtained with 10 g of gunpowder was deemed close enough to the required 313.0 m/s to replicate firing at 150 yds. 14 g was found to give an average muzzle velocity of 383.9 m/s, with the results shown in Table 3. This was regarded sufficiently near to the required 379.0 m/s to replicate firing at 75 yds.

<i>Amount of powder (g)</i>	<i>Achieved muzzle velocity (m/s)</i>
14	388.0
14	365.1
14	398.7

Table 3. Replicating Firing at 75yds

Conclusion

Due to the variable nature of gunpowder in the replica musket, it was decided that obtaining the calculated muzzle velocities exactly was not necessary, and small differences were tolerable. 10 g of the 3A/G12 mixture provides a close enough muzzle velocity to that desired for the 150 yds, whilst 14 g would be used for 75 yds.

Wound Effects

Target Analysis

At the battle of Culloden, the target was a Jacobite warrior wearing a woollen garment known as a plaid, which in various forms could constitute a kilt, a shirt and or a waistcoat. The armour consisted of large shields known as targes. The targe was constructed from an irregular number of thin planks of pine glued edge to edge, which was then laid crossways over another series of similar planks, so the grain of one is set across the other. This cross ply construction made the shield stronger and much improved sword or bullet-

stopping capabilities. The front of the targe was then covered in cowhide and nailed at the back. Targes were between 18 and 24 inches in diameter, with the wood around half an inch thick. Based upon this data, and ignoring some of the decorative features, a replica was produced from pine cross ply, and covered in cow leather.

The targets used to mimic the human torso were produced from a mix of water (85% by weight) and ballistic gelatine (15% by weight). This mix has a similar density (1.06 g/cm^3) and elastic modulus to human tissue, while accounting for variances in density within a real human torso. A thick woollen blanket was cut to cover the face of each target block. This represented the likely clothing worn by Jacobite forces during the battle. In some trials, it was wetted to assess any differing effects, as claimed by some historians.

Wound Effects Experiments

Eight experimental firings were used to examine the wounding effects of the technical replica and deformation of the lead shot. The same range set up described earlier was used, with a high speed camera focused on the target end in order to capture temporary cavitation effects. The technical replica Brown Bess was mounted on the stand at the SAER, and fired using an appropriate amount of modern gunpowder to achieve the terminal velocity expected at the likely distance of engagement with the enemy.

Experiment investigating Effect on Gelatine Block at 150 yds

The first experiment was designed to simulate the effect of the musket shot hitting a man in the torso at 150 yds—the likely distance of engagement. A blanket was placed around the gelatine block to replicate clothing. An entry wound 38 mm across was inflicted, and an exit wound of 65 mm. The maximum permanent cavitation was around 40 mm. It is assessed that this level of damage to the ballistic gelatine block represents a catastrophic effect on a human torso at the likely maximum distance of engagement, assuming a strike to the torso.

Experiment investigating Close Distance Engagement (75 yds)

Next, the effects of the musket shot hitting the chest of a man at 75 yds were measured. 14 g of gunpowder was used to achieve the 379.0 m/s muzzle velocity to simulate this engagement range. The high-speed camera captured evidence of some extremely large temporary cavitation, stretching the gelatine block to twice its original height and volume. The entry wound was 48 mm across, and exit was around 55 mm. The maximum permanent cavitation was 80 mm across, and the wound track had forced off a chunk of

ballistic jelly. The temporary cavitation is much greater at 75 yds compared to 150 yds, meaning that considerably more damage would have occurred, that would almost definitely have been fatal.

Experiment to measure the Penetration of Replica 18th Century Armour (150 yds)

The third experiment was designed to measure the effectiveness of battlefield protection available at the time of the battle of Culloden. A smaller mould of ballistic gelatine was used, replicating the thickness of a human arm, which would be supporting a targe in battle. Both the targe and the ballistic gelatine were penetrated, with a clear wound track visible through the depth of the gelatine block. Small pieces of wood and woollen material were dragged into the wound track. The entry wound was 20 mm in diameter and the exit wound 25 mm. Considerable translation occurs, with both the targe and the gelatine block knocked off the target frame. Permanent cavitation in the form of small bubbles in the gelatine block could be seen, 38–40 mm in diameter.

The presence of an exit wound in the gelatine block shows that not all of the kinetic energy was transferred to the gelatine block. However, the translation of the apparatus implies that the force may be great enough to knock over a soldier holding a targe. A considerable amount of the displaced wood from the targe could be seen in the ballistic gelatine block. This would drag any dirt and pathogens into the wound, likely to cause death by secondary infection if the soldier survived the impact.

Experiment investigating Effect on Replica Armour with Steel (150 yds)

The fourth experiment was a repeat of the previous, but with a 1 mm steel plate placed in front of the targe to replicate the reinforced shield sometimes utilised. The steel plate was easily penetrated, as was the targe. This proved that the steel plate provided little additional resistance to the shot. However, the steel may have improved the targe's performance against other hand-held weapons such as axes or maces.

Experiment investigating hitting two Ballistic Gelatine Blocks with Clothing and a Pork Ribcage (150 yds)

The fifth experiment was designed to evaluate three effects. Firstly, the shot hitting bone, achieved by placing a pork ribcage between the clothing and the gelatine block; secondly, another gelatine block was placed 20 cm behind the first to see whether two Jacobite soldiers may be incapacitated by the same shot; thirdly, the second block was placed behind six layers of fabric that were saturated with water. This would investigate the theory that wet blanket may prevent penetration by the lead shot.



Fig. 3. High Speed Camera Footage Showing Temporary Cavitation

Both gelatine blocks were penetrated, and large temporary cavitation was captured on high speed camera, shown in fig 3. Significant debris from clothing and pork ribcage is visible in the wound track of the first gelatine block. There is fabric debris in the second. This proved that the same round could well incapacitate two or more (closely spaced) Jacobite soldiers. It also disproves any idea that wet clothing may protect against penetration from lead shot. It was evident that a large amount of debris gets dragged into any cavity formed by the shot, likely to lead to infection if the wound is survived.

Experiments examining the Effects on Modern ceramic body armour (CBA) (150 yds)

The next two experiments were designed to compare the Brown Bess effects on modern day battlefield protection; CBA with and without a ceramic plate. Without the ceramic plate, the shot hit the fabric lining of the CBA, perforating it. The shot was caught inside the fabric and bulged the inside lining. The shot itself became deformed, with the appearance of it having been squashed. The inside of the fabric protruded sharply around 2-3 inches into the body behind the armour. With the ceramic plate inserted, the plate was



Fig. 4. Damage to Ceramic Plate

shattered and only a slight bulge occurred to the fabric. The damage to the ceramic plate is shown in fig 4. The high speed footage appeared to show the lead shot shattering.

While the CBA stopped the shot, the behind armour effects were considerable. It is assessed that the lead shot would incapacitate a man wearing CBA without ceramic insert plate. With the plate, incapacitation was unlikely to have occurred, but the wearer would probably have been knocked over.

The Effects of Musket Balls striking Sharp Metal, such as Sword Blades (150 yds)

Previous archaeological investigations at Culloden have uncovered musket balls which appear to have been deformed, perhaps by striking a sword blade or other metallic item such as a belt buckle. The former hypothesis was drawn from musket balls which had been almost cleaved in two, leaving the two halves hinged like a scallop shell (Pollard 2005). An attempt was made to replicate this circumstance by positioning mesh wire garden fencing at the end of the range, with a 'soft capture' box containing rubber chunks behind it. The fencing used was steel with plastic coating. The horizontal and vertical strands of the fence formed 45 mm by 45 mm squares. The soft capture box was intended to decelerate and contain the lead shot.

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Unfortunately, the soft capture box failed to adequately decelerate the shots, resulting in deformation occurring on hitting the back wall of the box. It was not therefore possible to examine whether the shot had cleaved. All shots caused dislocation and bending of the strands in the fencing, or the removal of one side of a square in the fencing. This implies that metal, such as a belt buckle, would be unlikely to stop a lead shot.

Terminal effects summary

The effects demonstrated using ballistic gelatine at realistic engagement ranges have shown that if struck by a lead shot, the human body will at the very least be incapacitated, and most probably fatally injured. In this respect, the ballistic performance of this weapon system can be said to be excellent, with its effect on modern CBA showing it to be comparable to modern weapons (except enhanced penetrating ammunition). It would certainly cause attrition to advancing enemy who entered the zone where the shots were fired.

Accuracy

The experiments have not investigated the issue of accuracy of the weapon, which has obvious ramifications for the overall effectiveness. However, the technical replica used during the project did display a consistent level of performance, with entry holes on a witness screen behind the targets often overlapping, and all occurring within an area of an A4 piece of paper at a range of 20 m. Given the reports of extreme inaccuracy, this result was surprising. However, many variables that are known sources of inaccuracy were eliminated during the range sessions. The recoil of the weapon is known to be huge, and likely to be the largest cause of variability, as it would be impossible to hold the weapon still when firing. The more consistent modern gunpowder used would also have reduced the muzzle velocity variation, which in turn affects the trajectory.

Conclusion

The aim of the project was to conduct a detailed study of the effectiveness and capabilities of the 18th century Brown Bess musket. Experiments were designed and conducted which investigated the ballistic effects of the Brown Bess, and answered the questions posed at the start of the project. A replica musket was created, which was able to fire replica cartridges with accurate recordings made. Having researched the historical accounts, key claims of the Brown Bess's capabilities were chosen for investigation. Experiments were then

designed to assess their legitimacy. In all cases, meaningful results were obtained, which could be related back to the historical evidence.

Gunpowder

Gunpowder in the 18th century was made using a lengthy procedure which contravenes modern health and safety regulations. The modern gunpowders that were sourced to fire the weapon were not as powerful per unit mass to the 18th century gunpowder in terms of muzzle velocity achieved. 15 g of modern powder was required to achieve the same velocity as 10 g of the old powder. This could be attributed to the modern powder not being designed to fire a musket, and so having different specifications.

Cartridges

Replica cartridges were successfully constructed following the 18th century method, using paper and lead shot that were a close match to the original.

Modelling

The computer modelling proved invaluable when calculating how to scale down the powder to achieve the correct muzzle velocities for the terminal effects. The models also provided information about the range of the weapon, which could not be performed experimentally. The maximum calculated range was around 1,200 m when firing at 35° of elevation, and 202 m when firing horizontally.

Wound Effects

All but one of the experiments examining terminal effects used a muzzle velocity equating to being hit at 150 yds (137 m). The damage caused to the target indicates that immediate death would be almost certain due to the large temporary and permanent cavitation. This confirms the effectiveness of the weapon at relatively long range, contradicting the historical accounts of it being ineffective at 100 yds (91 m). At 75 yds (69 m), the effects were even more damaging, causing much greater cavitation. It was also proved that a single shot could penetrate more than two soldiers, and would shatter bone, dragging fragments throughout the wound. The outer clothing layer was also dragged through the wound, along with any dirt and pathogens. If the soldier survived the impact, death would still be likely through secondary infection. The damage caused to the modern CBA again shows the harm that the shot could cause against today's armour.

BIBLIOGRAPHY

- Buchanan, B 1996 *Gunpowder: The History of an International Technology*. Bath University Press: Bath
- Crocker, G 1986 *The Gunpowder Industry*. Shire Publications: Oxford
- Hanger, G 1816 *Colonel George Hanger's Advice to all Sportsmen, Farmers and Gamekeepers*. Printed for JJ Stockdale: London
- Harding, D 1999 *Small arms of the East India Company 1600–1856, Volume III: ammunition and performance*. Forsight Books: London
- Hughes, BP 1974 *Firepower: Weapons Effectiveness on the Battlefield, 1030–1650*. Charles Scribner's and Sons: New York
- James, G (no date) *Britain's Brown Bess*. http://www.rifleshooter.com/featured_rifles/bess_092407/
- MacPherson, D 1994 *Bullet Penetration: Modeling the Dynamics and the Incapacitation Resulting from Wound Trauma*. Ballistic Publications, El Segundo, CA
- Mordecai, A 1845 *Report of Experiments on Gunpowder*. Washington
- Moss, G M, Leeming, D W & Farrar C L 1995 *Military Ballistics*. Brassey's: London
- Nonte, G 1969 *Black Powder Guide*. Stoeger Publishing Company: New Jersey
- Pollard, T 2005 *Culloden Battlefield: Report on the Archaeological Investigation*. GUARD report no. 1981, University of Glasgow
- Pollard, T and Oliver, N 2003 *Two Men in a Trench II: Uncovering the secrets of British Battlefields*. Michael Joseph: London
- Reid, S (in press) 'The British Army' in Pollard, T (ed) *Culloden 1746—The History and Archaeology of the Last Clan Battle*. Pen and Sword: Barnsley
- Richardson, T 1999 'Ballistic testing of historical weapons', *Royal Armouries Yearbook 1998*. Royal Armouries. 50–52.
- Robins, B 1742 *New Principles of Gunnery*. London
- Sellier K G & Kneubuehl B P 1994 *Wound Ballistics and the Scientific Background*. Elsevier: Amsterdam
- Textbook of Ballistics and Gunnery 1984, Vols I and II*. Her Majesty's Stationery Office
- Thompson, A L 1969 'The Brown Bess Musket', *Guns Review*
- Willegal, M, 1999 *The Accuracy of Black Powder Muskets*. www.willegal.net/iron_brigade/musket.pdf

EXHIBIT 2

**Colonial Era Firearm Bullet Performance: A Live Fire Experimental Study
for Archaeological Interpretation©**



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With contributions by Daniel M. Sivilich and Daniel T. Elliott

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Introduction

Firearms were a central feature of combat for the past millennium and a significant vector of political, ecological, and cultural change. Guns entered the New World as a rather refined technology that became a causal factor in Post-Columbian developments. Guns, gunpowder, and projectiles affected interethnic, colonial, and political relations and were a major point of commerce and trade. They also deeply impacted the ecology of the New World. To address these kinds of issues, archaeologists need analytical tools to understand why gun parts failed, what types of firearms fired discovered projectiles, and the meaning of projectile distribution found on archaeological sites created by Colonists, American soldiers, traders and hunters, and Native Americans. A systematic archaeological study of guns is, however, only beginning.

In recent years, battlefield and conflict studies have emerged as a significant focus of archaeology internationally. This present study intends to enhance archaeological research on these topics by using multidisciplinary experimentation to reveal residue patterns associated with pre-modern gun use. Attempts to interpret the battlefield evidence indicate the need for specialist expertise to explain the origins of firepower. This information is scattered across various disciplines, with respective researchers not adequately sharing information with one another. Forensic scientists, firearm examiners, and engineers have developed techniques for the study of firearms, but these are rarely addressed by archaeologists.

Experimental archaeology has emerged as a rigorous approach to the study of material reflections of human behavior. This is an increasingly refined field that lets archaeologists develop insights and methods for making behavioral interpretations of things in the archaeological record. To study firearms, archaeologists need to design and carry out appropriate experiments and draw on technical methods developed by firearm examiners, engineers, and physicists. Recent battlefield archaeological investigations have given new impetus to identifying the rifling characteristics of historic rifled firearms, the external ballistic capability of such firearms, and the combat efficiency of such arms. The goal of this study was to collect information on the ballistic capability of late eighteenth smoothbore firearms.

With some modern exceptions (see External Ballistics section), there have been few controlled studies of flintlock and percussion ignition system small arms combat efficiency. Neither have there been external ballistics studies since a British experiment in 1840 (Hughes 1983; 1969; 1974). This study is a byproduct and outgrowth of conversations and personal interest associated with the recovery of fired and dropped Colonial and British musket balls from the Parker's Revenge site, a part of the April 19, 1775 battles that began the Revolutionary War in earnest. The Parker's Revenge project at Minute Man National Historical Park directed by Margaret Watters Wilkes (2016) was responsible for bringing the team together that eventually conducted the live fire research effort.

The results of this live fire experiment with Colonial and Revolutionary War firearms is a beginning for the investigation of late pre-modern gun use. To determine what happens when large-caliber lead balls were used in combat or hunting we observed impacts of experimentally fired balls into ballistic gelatin, an accepted tissue simulant with end coverings to simulate

clothing of the era, and into a sand backstop. We also used a wooden palisade made up of dry loblolly pine, green loblolly pine, live oak, and maple palings to obtain bullet impact information. Projectile deformation associated with varied ranges were catalogued. The results of these experiments will permit archaeologists to better interpret recovered projectiles.

The study goals were to collect data and conduct live fire experiments with high-quality faithful reproductions of typical and common Colonial and Revolutionary War weapons. The study activities were designed to benefit several audiences:

- 1) those interested in the history of firearms;
- 2) re-enactors who will use the information in creating more authentic presentations;
- 3) professional historians, archaeologists, and interpreters who either deal with firearms or how firearms were used; and
- 4) firearm examiners who can use the information to exclude historic bullets and cartridges that are sometimes found on crime scenes from consideration and/or correctly assess black powder and reproduction firearms that are sometimes used in shooting incidents today.

The live fire experiments were designed to capture information of flintlock firearm performance and capabilities that will benefit the goal audiences in their understanding and interpretation of archaeologically recovered spherical lead balls. To achieve these objectives, we designed the experiments to collect data on:

- 1) the velocity, range, and ballistic performance of common spherical lead balls of the type used in the Colonial era.
- 2) factors that could cause variation in ball impact, and
- 3) how deformation of lead balls can be linked to velocity, impact range, and target media.

This report is well illustrated for the simple purpose of providing the reader with illustrations of weapon types, bullets, bullet deformation, etc. The extensive use of figures is, we believe, important to visualize and make clear the complex elements of firearms external and terminal ballistics that would result in a far wordier presentation otherwise.

Components of the Live Fire Experiment

The live fire experiment used common types of French and Indian War and Revolutionary War flintlock firearms. Other components of the experiment included the firing range, consideration of the black gunpowder used as a propellant, standardization of the lead balls, the construction of authentic style cartridges, and the methods of data collection.

Firearms Used in the Experiment

Seven flintlock shoulder fired firearms were used in the live fire experiment. The seven are a reasonable representation of guns commonly used in the French and Indian Wars and the Revolutionary War. They are all custom-made replicas of actual Revolutionary War flintlock firearms. One Colonial fowler, a copy of the .580-caliber Thomas Earle Fowler represents the type of weapon used by Colonial militias and minute man companies. Two British Long Land Pattern Brown Bess guns, the 1742 pattern and 1756 pattern in .76-caliber, represent the standard British infantry firearm used in the French and Indian War as well as the American Revolution. Another common British gun of the era is the Artillery Carbine in .65-caliber, which also represents the British Officers Fusil and the British Sergeants Carbine. Two French patterns, 1728/41 and 1763/66 were also fired. The pattern 1728/41 has a slightly oval bore, as does the original from which it was copied. The bore in .70-.71-caliber. The French 1728/41 musket was also used in the French and Indian Wars as well as by Revolutionary War militia companies and militiamen. The pattern 1763/66 has a .68-caliber bore. The seventh gun was a replica 1740 Potsdam musket, .73-caliber, of the type often carried by Hessian units recruited by the British.

The experimental firing was conducted over a three-day period, November 14-16, 2016 near La Grange, Georgia.

Firing Range

For this study a 100-yard range was constructed to contain or concentrate the fired projectiles in a safe and manageable way. At 100 yards a 7.5-foot high palisade wall was constructed from freshly cut oak and pine logs. Directly in front of the palisade wall a sand backstop 5.5-foot high by 10-foot wide was mechanically piled using fine clean sands. These media were chosen to replicate soil impacts and wood impacts of various types to add to the data of the study. In addition to the palisade and sand backstop a shooting bench was constructed to provide a stable base for consistent shooting. While demonstrating accuracy was not the goal of the live fire experiment, the bench and target provided a stable aiming point for all shots.

The range was established with safety as the priority. A large hill provided a natural backstop at 200 yards and a safe zone extended another 1500 yards. The range, located on private lands with limited access, thereby provided access control for personal and equipment.



Figure 1. The firearms used in the live fire experiment. Top to bottom, British Artillery Carbine, British 1742 Long Land Pattern musket, British 1756 Long Land Pattern musket, French 1728/41 musket, French 1763/66 musket, Thomas Earle fowler, and a Potsdam 1740 musket.

One team member was designated as range safety officer, with all other shooting team participants also remaining vigilant. Prior to all firing the safety officer, William Rose, announced ready and proclaimed the range hot. After firing the weapon was cleared and a recovery team proceeded down range to recover the projectile. When a hangfire or flash in the pan occurred, the weapon was held in place for a count of 30 seconds, the pan cleaned and re-primed, then an attempt to fire the weapon again. The range was declared clear only when the weapon was successfully discharged.

The palisade wall was constructed to provide additional data on impacts of projectiles on selected wood species. The trees selected; live oak (*Quercus virginiana*), loblolly pine (*Pinus taeda*), and red maple (*Acer rubrum*) were all about four-inches in diameter. Each is a common species found along the east coast, which allowed for a reasonably accurate recreation of a Colonial block house palisade wall. Constructed with two 25-foot long 6-inch truss supports screwed in place with 10-inch screws, the log palings were placed between two living oaks that were 20-feet apart. These acted as addition supports for the palisade line. Each 4-inch post was placed in a 12-inch deep post hole and backfilled after wood post placed. After placement, baling wire was utilized as lashing to secure the post in place. After all posts were in place they were trimmed to the same length. It was not the intention for the palisade to act as a backstop but rather to add data on bullet impact and deformation. Because of the chance of projectiles passing though the gaps or wood post, a tarpaulin was placed on the backside of the palisade to track projectile trajectory.



Figure 2. The area of the firing range. The blue line is safety zone, black line is the 100-yard range, and the yellow line delineates the western property boundary along a stream.



Figure 3. Patrick Severts seated at the shooting bench and taking aim at the 100-yard range.

The sand backstop in front of the palisade wall not only provided a backstop for projectiles but also offered soil impact data. For this, clean loose sands were chosen to minimize escapement or deflection. After each firing a metal detector sweep of the backstop was conducted to expedite the locating of the fired projectile and to keep the sand free of potential hazards. Just to the front of the sand backstop a target stand with a silhouette target provided a defined aiming point. The

target frame was constructed of 4x4 inch treated pine lumber with a sheet of fiberboard as a target backing. A man-sized head and torso standard paper silhouette target was affixed to the fiberboard.



Figure 5. Charles Haecker and Corinne Rose standing on either side of the target frame. Note the sand backstop behind the target and the palisade wall behind the backstop. The stake in front of the target is at 94 yards from the shooting bench, with the palisade at 100 yards from the bench location.

Black Gunpowder Propellant

In this study, we used Swiss FFg black gunpowder as the priming and propellant charge in all weapons. Only the charge weight was varied among the guns fired and for purposes of achieving lower velocities for shooting into tissue simulant. Dodd (2006:31) defines black powder as:

“Black powder, by its very nature, is a true explosive. The smallest of sparks is sufficient to effect ignition. On ignition, a large quantity of bluish-grey smoke is generated and a characteristic sulfurous residue is deposited on both the weapon and the shooting hand. The Chinese are credited with its discovery and the discovery of the explosive properties of the mixture of substances we know as traditional gun powder — sulfur, charcoal, and saltpeter (potassium nitrate). It is suggested that gun powder may have been used in the manufacture of fireworks well before its application to firearms and warfare. Only the manufacturing process has been refined over time.”

The origin of black gunpowder is still debated in academic circles, but it is largely agreed to have originated in China in the eleventh century and spread to Europe by the late thirteenth or early

fourteenth centuries (Buchanan 1996). The first black powder was hand mixed and is referred to as serpentine powder (Hall 1996:87-88). The black gunpowder used in this study is much more refined and is referred to as corned gunpowder. Corning, the wetting of the dry mixture, stamping, and glazing, as well as other manufacturing processes, began in the mid-1400s and largely supplanted serpentine powders by about 1550. The corning process was refined over time, but for all practical purposes corned black gunpowder was the only type used in the New World after the mid-1500s (Hall 1996; Tascón et al. 1996; Howard 1996). The Swiss® brand corned black gunpowder used in our experiments is considered to be among the best at producing reliable and replicable results in comparisons with other black gun powders and black powder substitutes manufactured today for sporting purposes (Haag 2001; 2012).

Historically, the amount of black gunpowder used in various weapons in the eighteenth and early nineteenth centuries varied substantially. One source (Force 1846:667-68). list powder charges for muskets as:

"In Committee of Safety, May 29, 1776...The Committee appointed to consider of a proper mode of providing Cartridges for the different bores of Fire-Locks in the hands of the Associators report, that the practice of our Commissary, upon the authority of Books, is, two-fifths of the weight of each Ball to a charge of Powder, which proportion has been ascertained by actual experiment, as lately reported by a Committee appointed out of the Battalions in this City, as published in the publick prints, adopted by this Board and entered on our Minutes."

The Committee of Safety then listed several bore sizes in gauge or balls to the pound with their respective pennyweight and grain weight powder charges. The list, with a conversion to standard caliber measurements and powder charge by grains is:

Balls to the pound	Caliber in inch	Powder charge in grains
13	.777	236
15	.695	204
17	.665	180
19	.637	160
21	.618	146
24	.588	128
30	.533	102

Ayde (1800:60) lists a series of gunpowder charges for common European muskets of the late eighteenth century, but does not list the calibers, although they were all in the .69 -.75-caliber range for known muskets of the time.

English - 7 Drams = 192.5 grains

Hessian 6 Drams = 165 grains

Austrian -5 Drams = 137.5 grains

Dutch - 4 Drams = 110 grains

French - 3 Drams = 82.5 grains

Another source (de Marolles and Cleator 1789:200-201) suggests: "Some determine the charge of a fowling piece, by the weight of the ball of the exact size of the caliber; estimating the weight of the powder at one-third of that of the ball, whether it is proposed to shoot with ball or with shot,..."

Spearman (1828) in his British Gunner treatise states the following charges were standard since 1775:

Musket:

Proof charge: 23.334 drams (642 grains)

Service charge: 6 drams (165 grains)

Exercise charge (for blanks): 5 drams (138 grains)

Carbine (Rifle Bore)

Proof charge: 15 drams (413 grains)

Service charge: 4 drams (110 grains)

Exercise charge: 4 drams (110 grains)

Carbine (Musket Bore)

Service charge: 5.5 drams (151 grains)

Exercise charge: 4.5 drams (124 grains)

Spearman also stated: "The service charges given in this table, although established by authority, are too great, and might be reduced by about one-fourth. They have not been altered since 1775, while the strength of the powder has been increased in nearly a two-fold ratio since that period."

Klatt (1999) reported on two surviving Revolutionary War era cartridge packets, containing buck and ball loads. Both packets are dated 1777 and had powder charges of around 115 grains (7.45 grams). This charge is consistent with Spearman's observation of reducing the approved British powder charge by one-fourth to account for the availability of better quality gun powders.

The range of black powder charge sizes for any given caliber is varied as these and other sources cited later demonstrate. We choose to use a 110-grain black powder charge in .69-caliber to .75-caliber guns including the priming charge as it most closely approximates the Spearman recommendation and is consistent with the known charges in surviving Revolutionary War cartridges. For smaller caliber firearms we choose to use an 85-grain powder charge including the priming charge. We also used reduced charges to lower the muzzle velocity when firing at ballistic gelatin in order to capture the bullet in the gelatin. Powder measures showed only 0.1-gram variation in weight among any given charge size.

Lead Spherical Balls Used in the Experiment

Information on the diameter and weight of Revolutionary War musket and fowler balls comes largely from the archaeological record. There are few surviving Revolutionary War spherical balls from non-archaeological contexts that are available or have been studied. Klatt (1999) reported on two surviving Revolutionary War era cartridge packets, all of which are buck and ball loads. Both packets are dated 1777 and contain 10 buck and ball cartridges each. One packet was still sealed, but the second was open. The cartridges in the open packet were removed and examined. The bullet caliber is noted as only .69-caliber (17.5mm), although it appears no formal measurements were taken. The buckshot is reported to be .32-caliber (8.1mm). The average weight of the balls is reported to be 490 grains (31.75 grams), for the buckshot 150 grains (9.72 grams), and the powder charge 115 grains (7.45 grams).

Thomas (1997:106-108) illustrates and provides measured diameters and weights for fifteen pre-Civil War .69-caliber (17.5mm) spherical balls. The balls vary 0.640 (16.2mm) to .0715 inch (18.1mm) in diameter and vary in weight from 423 to 700 grains (27.5 to 45.3 grams). Thomas' observations are based on source material from a variety of origins, but the ranges in weight and diameter are far greater than the bullets used for this study. The same is also true for the range of variation in the Brown Bess caliber bullets reported from several French and Indian War sites as well as Revolutionary War sites (Thomas 1997:105) with a range in diameter of 0.625 inch (15.9mm) to 0.695 inch (17.7mm) and a weight range of 343 to 472 grains (22.2 to 30.65 grams).

Wilkes (2016:315) provides weights and diameters on fifteen British and nine Colonial fowler balls that were fired on the first day of the American Revolution, April 19, 1775, at the Parker's Revenge site in Minute Man National Historical Park. The British spherical range in weight from 364.2 to 483 grains (23.6 to 31.3 grams) and the calculated diameters range between 0.639 to 0.702 inch (16.23 to 17.8mm). The Colonial fowler spherical balls ranged in weight from 126.5 to 381.1 grains (8.2 to 24.7 grams) and in diameter from 0.449 to 0.649 inch (11.4 to 16.5mm). Similar findings are reported by Sivilich (2016) in his spherical ball study and by Harding (2012) in his study of lead shot from the seventeenth century English Civil War.

One of the earliest known studies of bullet performance and penetrations was conducted by a U.S. medical officer on behalf of the U.S. Army Ordnance Department in the early 1900s. La Garde (1991:36) in his pre-World War I study of gunshot injuries compiled a table of 'early' small arms ammunition, which included the pre-1851 round ball. He reported the round ball to have ranged in diameter from 0.7559 inch to 0.6929 inch in diameter and with a weight range of

484 to 584 grains. He also noted the initial muzzle velocity of these early balls to range from 590 to 754 feet per second. La Garde does not provide a source for his data, and it seems in part inaccurate, but it likely reflects the loss of accurate information on bullet diameter and weight for spherical balls that occurred after the mid-nineteenth century shift to conical or cylindro-conical bullets.

Dr. Lawrence Babits conducted a series of live fire experiments to determine the accuracy of buck and ball loads at different ranges. He conducted the experiments over several years with French and U.S. regulation muskets (Babits 2002). His report used documentary sources and compared them to his live fire experiments. He found that the ball was reasonably accurate out to 100 yards, but the buckshot rarely hit the target at that range. Buckshot would hit an intended target at 25 to 30 yards, but beyond that range it was largely a matter of coincidence if a buckshot hit its intended target.

The spherical balls used in the live fire experiment are commercially cast soft lead bullets (see Appendix C for pXRF trace element information). The experimental spherical ball weights show a minimum of 1.5 grain (0.1-gram) to a maximum of 4.6 grain (0.3-gram) weight variation in the 20% sample weighed. The measured ball diameter also showed very little variation, being about 0.001 to 0.003 inch among all the balls measured. They have far less variation in weight and diameter than any of the published historical ball diameters or archaeological specimens reported. The balls are less than bore size, except for the .580 ball which is bore size for the Thomas Earle fowler. Typically, balls were less than bore sized to allow ease of loading, especially after multiple rounds were fired which caused black powder fouling in the bore. The common term for this is windage.



Figure 6. Unfired cast lead balls used in the experimental firing. L to R, .315 buckshot, .282 buckshot, .520 ball, .580 ball, .626 ball, .663 ball, and .69 ball.

Cartridges and Cartridge Paper

Prior to the live fire experiments Corinne and William Rose rolled a series of cartridges in each of the calibers to be used following eighteenth century guides on cartridge construction. Proper weight laid paper in a trapezoid shape was rolled around a wood former. A ball or a ball and

three buckshot were placed in one end, the top twisted closed and the former removed. The appropriate powder charge for the caliber was then poured into the other end of the cartridge, twisted closed and the excess laid paper folded over to form a tail. Linen twine was then wetted and tied below the ball or ball and buck to hold the bullet in place. Finally, a ball point pen was used to mark the completed cartridge with the type and ball diameter.

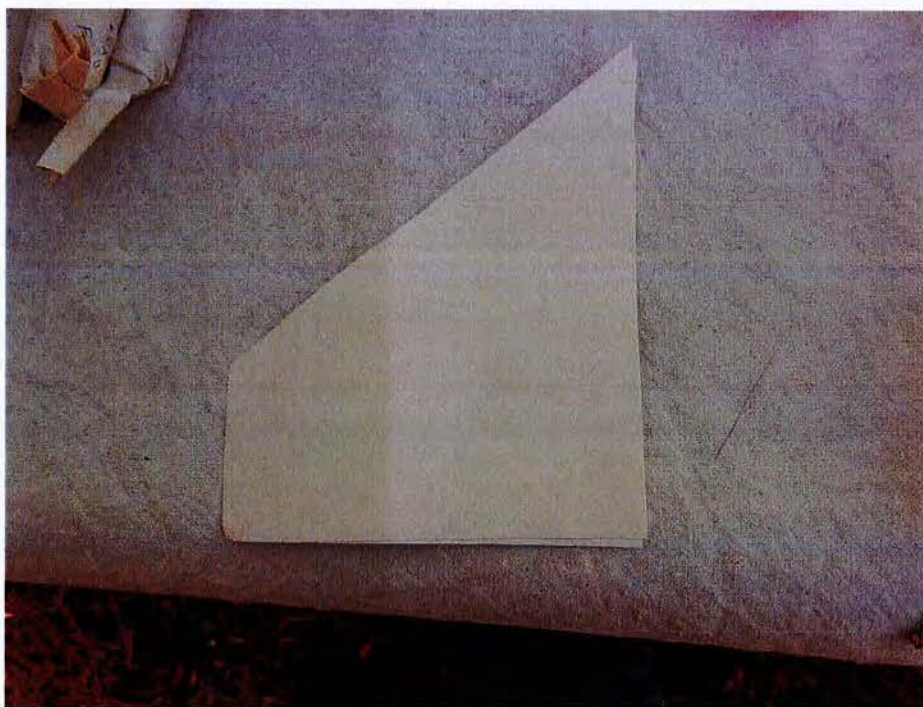


Figure 7. Laid cartridge paper cut to standard form and ready for rolling cartridges.



Figure 8. Corinne and William Rose rolling cartridges in preparation for the experimental firing.



Figure 9. Completed cartridges with notes on the laid paper body denoting ball size and intended firearm.

Live Fire Experiment Methods

The live fire experiments were conducted on November 14-16, 2016. Each firearm was loaded for the experimental firings by a single individual. Each firearm was fired in either a 10 shot or 5 shot string by the same individual. Shooters were changed for each gun. The guns were fired from a bench rest, not to achieve accuracy for each shot, but to enable the use of high speed videography to capture the ball as it emerged from the muzzle as well as record initial muzzle velocity.

Nathan Boor of Aimed Research® provided and operated a Phantom V611® high speed camera that was calibrated for each shot string. The camera recorded imagery at approximately 6,900 frames per second in Raw format. For each shot string, the gun was placed on the bench, the height from muzzle to ground surface was recorded. Each shot had the ball diameter and weight noted. Also recorded were the weight of the propellant charge, the calculated muzzle velocity, temperature, wind speed, and humidity. Barometric pressure was obtained from the local weather service daily records.



Figure 10. High speed camera setup in progress with personnel measuring muzzle height above ground surface and preparing to calibrate the camera.

A LabRadar® unit, which is a Doppler radar tracking device, was set up to acquire initial muzzle velocity data. The unit was unable to acquire any data due to the amount of gas, flame, and smoke emanating from the muzzles of the flintlock muskets. The radar unit was moved down range in several increments until it reach nearly 20 feet from the muzzle. It was unable to acquire any data and was then retired from the project.



Figure 11. LabRadar® Doppler radar unit. Due to the extensive downrange gas and smoke flare from firing the unit was not capable of acquiring downrange velocity data and was withdrawn from service.

Most shots were fired at a range of 94 yards using a man-sized head and torso silhouette target mounted on a 4x4 treated pine frame. Buck and ball loads were fired at ranges of 25 and 30 yards with the target frame moved to each of those distances from the firing bench. On November 16 shooting was confined to firing three guns at blocks of Clear Ballistic® gelatin as well as some offhand shooting done to record the flintlock function and the nature of the recoil.

After each shot was fired two to three team members moved down range with metal detectors to search for and recover the fired ball. Metal detectors employed included a Minelab CTX 3030®, a Minelab E TRAC®, and a Fisher F75®. Recovered bullets were bagged separately and labeled with the gun type, shot number, ball diameter, muzzle velocity, date, and any other relevant information.

The Thomas Earle Fowler, .58-caliber, was fired on each of the three days of shooting. No brushing or cleaning between shots was done on the first day. Twelve shots were fired with one misfire on shot eleven on the first day. The load was 85 grains of 2F Swiss Black powder with a .520 ball rolled in cartridge paper. Five shots were fired on the second day using 85 grains of powder and an unpatched .580 ball. No misfires occurred. On the third day four shots were fired using the unpatched .580 ball. Two shots were fired with 85 grains of powder and two with 75 grains of powder. No misfires occurred. The fowler was later fired, after resting several hours, using six buckshot. Two misfires occurred and the flint was replaced. A total of 23 shots were fired from the fowler with one misfire on the eleventh shot, and two misfires after 19 shots when the flint was replaced and two additional shots were made with no misfires. The fowler was cleaned each evening.



Figure 12. Man-sized torso paper target and target frame used as an aiming device during the firing. Hits were patched with duct tape and the shot noted. The uncovered holes in the target show a buckshot and ball hit from a buck and ball load.



Figure 13. Metal detecting underway to recover a ball after a shot at the 94 yard range.



Figure 14. British and French gunflints used in the experimental firing. The top left is a British unused flint and the top right flint is fully expended. The bottom flint is a French style unused flint.

The *British Artillery Carbine* was fired ten times on the first day with three misfires occurring, two on shot 7 and one on shot 9. The bore was dry brushed for safety after each shot, but not thoroughly cleaned until completion of the day's shooting.

The *British 1742 Long Land Pattern musket* was fired five times on the second day with two misfires on shots 1 and 5. The bore was dry brushed for safety after each shot, but not thoroughly cleaned until completion of the day's shooting.

The *British 1756 Long Land Pattern musket* failed to fire and after four misfires was withdrawn from use until the touchhole was cleaned using a vent pick and the loaded charge could be safely fired. The gun was not properly cleaned after its last use and carbon fouling at the breech prevented the powder charge from reaching the touchhole. Work with a vent pick helped clear the hole and fouling to the point where sufficient powder grains worked into the chamber via the touchhole allowed the gun to be safely discharged. The gun was given a thorough cleaning that evening. The 1756 Long Land Pattern was fired twelve times on the third day. Ten shots were fired at the Clear Ballistic® gelatin and two additional live fire shots were made in the offhand position to film details of the working of the flintlock mechanism and observed the full firing sequence as well as recoil. The bore was dry brushed for safety after each shot, but not thoroughly cleaned until completion of the day's shooting.

The *French 1763/66* was fired fifteen times on the second day with buckshot and ball loads. The range was decreased to 25 yards for the first 10 shots. Shot 1 had a spread of 12 inches for the buckshot and ball. Shot 2 had a spread of 8 and 9 inches from the ball to the two buckshot that struck the target and target frame post. Shot 3 had a spread of 9 and 15 inches. Shot 4 had a spread of 8 and 9 inches with one buckshot nicking the target frame post. Shot 5 had a spread of 9 and 15 inches.

Shot 6 did not strike the target. Shot 7 had a 9-inch spread between the ball and one buckshot. Shot 8 had only a single buckshot hitting the target. Shot 9 did not strike the target. Shot 10 had a 6-inch spread between the ball and a buckshot.

The target was moved back to 30 yards and five more shots were fired with buckshot and ball using three different shooters. Shot 1 had no hits, but the ball and one buckshot were recovered at 100 yards in the soil backstop. Shot 2 had a spread of 9 inches between the ball and a single buckshot. Shot 3 had only a single buckshot hit the target, but the ball and a buckshot were recovered from the backstop at 100 yards. Shot 4 did not strike the target. Shot 5 had a 5-inch spread between the ball and one buckshot. The bore was dry brushed for safety after each shot, but not thoroughly cleaned until completion of the day's shooting.



Figure 15. A buck and ball load hit on the paper target at 25 yards fired from the *French 1763/66* musket. The ball struck the center mass with the three buckshot striking, two at the lower 9 ring and one lower and left in the 8 ring.

The *French M1728/41* musket was fired five times on the first day with three misfires occurring on shots three and four. The bore was dry brushed for safety after each shot, but not thoroughly cleaned until completion of the day's shooting.

The *1740 Potsdam musket* was fired five times on the second day with one misfire occurring on the fourth shot. The bore was dry brushed for safety after each shot, but not thoroughly cleaned until completion of the day's shooting.



Figure 16. Charles Haecker firing the 1740 Postdam musket. The musket misfired with only a flash in the pan.

The live fire experiment resulted in the firing of 74 spherical balls and 63 buckshot. The breakdown for each caliber fired by number of shots fired with recoveries noted, and total number of balls recovered per caliber.

12 - .520 balls were fired – 6 known shot sequence recoveries – 2 unknown attribution – total 8=75%

19 - .580 balls were fired – 9 known shot sequence recoveries – 1 unknown attribution – total 10=52%

23 - .626 balls were fired – 10 known shot sequence recoveries – 9 with unknown attributions – total 19=82%

20 - .69 balls were fired – 5 known shot sequence recoveries - 6 unknown attribution – total 11=55%

63 .282 and .315 buckshot were fired in 18 separate shots – 2 known shot sequence recoveries - 8 with unknown attribution- total 10=16%

Total ball and buck fired 137 - Total known recoveries 32=23% Total unknown recoveries 26=19%. Total recovered 58=42.3%

Principles of Firearms Exterior Ballistics; Background to the Study

Exterior ballistics is the study of the performance of a bullet after it leaves the gun. As Lucien Haag (2006:214-215) observes there is a difference in what a ballisticians and a forensic scientist, or for our purposes an archaeologist, is seeking in studying bullet performance. The forensic scientist or conflict archaeologist is seeking to reconstruct a shooting incident or event based on residual physical evidence, the artifact, and knowledge of one or more types of firearm ammunitions' ballistic properties and performance.

Essentially all firearms send a projectile toward a target in a like manner (Garrison 1993; Hueske 2006). The target is determined to be at a certain range, and there is a line of sight between the shooter and the target. When the bullet is fired from the firearm it has a line of departure, a bullet flight path, and an angle of fall which are effected by various physical forces, initial velocity, gravity, air resistance, wind direction, elevation, temperature, barometric pressure, and relative humidity. Each of these factors can be accounted for in one or more ballistic formulae that are used to calculate, with reasonable accuracy, how far the bullet will go before reaching a terminal velocity and return to earth. Likewise, formulae exist to calculate how much energy as foot pounds or joules, or kinetic energy a bullet will have at various ranges (Warlow 2005:130-134). These data become important to understanding bullets' ability to incapacitate or kill, or what may happen to a bullet that is an under or overshoot. Knowing this basic information allows the archaeologist to understand better the pattern of bullet deformation observed on a battle site, the patterns in which bullets are found, and better interpret an artifact assemblage.

External ballistics for post-1900 firearms and bullets are relatively well known and is the continuing subject of analysis as new smokeless gun powders and conical bullets are developed. Datasets on external ballistics and bullet performance are limited for the soft lead spherical balls and cylindro-concoidal bullets of the preceding centuries, especially the spherical lead ball. A great deal of lore and apocryphal information exists on the ranges and performance of these historical bullets. There are good summaries of test shooting, largely at pine boards and thick catalogs or telephone books (Mattoo 1969; Cayton 1984; Fadala 1988; Osborne 1777a, b; Herring 1971; 1972a, b, c), to determine bullet penetration at various ranges that were conducted in the nineteenth century and well into the twentieth century. These data are of limited value to the modern researcher. Thus, it becomes necessary to conduct first hand live fire research with a

variety of weapons under controlled experimental conditions to ascertain the behavior of spherical bullets and other projectiles that will enhance our understanding of lead bullet behavior of the pre-1900 era.

The background for several twentieth century studies of pre-nineteenth century bullet performance are summarized for comparative purposes. A somewhat anecdotal study of a live fire experiment using a circa 1600 German made combination matchlock and wheellock .75-caliber (19mm) musket was done in the early 1950s (Grancsay 1954). The experiment used a 430-grain (27.9 grams) lead ball with 80 grains (5.1 grams) of black powder which is approximately one-fifth the weight of the ball as prescribed in historical narratives. The experimenters fired the weapon at 10 feet (ca. 3 meters) at several pieces of original armor plate. A thin mild steel Italian shoulder defense plate dating to about 1575 was easily penetrated by the bullet. Another experiment employed a German, circa 1620, buttock defense armor. The ball struck the armor near the top edge and the metal was shot away, while an experimental firing against an early 1600s German heavy armor backplate resulted in only a slight dent to the armor. The author noted the ball literally disintegrated on impact with the heavy armor.

Late twentieth century well-controlled live fire experiments with historic and reproduction firearms are limited. One such live fire study is reported by Krenn et al. (1995) employing original matchlock, wheellock, and flintlock muskets and pistols held in the provincial arsenal at Graz, Austria. The test involved fourteen firearms dating from 1571 to about 1800. The experiment used modern rifle grade black powder with the powder charge calculated to be one-third the weight of the lead ball used in the specific weapon. The calibers range from 0.539 inch (13.7mm) to 0.811 inch (20.6mm). The bullet diameters and weights allowed for windage, but apparently, bullets were specifically cast for each barrel diameter, ranging from 0.531 inch (13.5mm) to 0.795 inch (20.2mm) for diameter and 147.5 grains (9.56 grams) to 758.3 grains (49.14 grams) in weight.

The powder charges ranged from 77 grains (5 grams) to 309 grains (20 grams) of black gunpowder. For safety reasons the guns were fired electrically thus no loss of pressure occurred through the touchhole. The authors do not report if the gunpowder charges were reduced by 10 to 15 grains to account for priming in the pan. Every bullet fired achieved supersonic speeds ranging from 1263 f/s (385 m/s) to 1748 f/s (533 m/s) suggesting they used a full charge without consideration of reducing the main charge to account for priming. This coupled with the loss of pressure at the touchhole due to the electrical firing likely artificially inflated the recorded muzzle velocities.

Krenn et al. (1995) do not report recovering or examining any bullets except those fired at a modern steel plate and historic mild steel breastplate armor as well as test fires into ballistic soap (10%). The study concluded that while the bullets had lethal capacity the arms themselves were largely inaccurate at ranges above 25 meters.

In 1998 the Royal Armouries in Leeds conducted a live fire test of a fifteenth century matchlock musket and a hand of the same century for the filming of a documentary (Richardson 1999:50-52). The description of the experiments is very limited with no information presented on the type of gunpowder used, how the weapons were fired, if the priming amount was subtracted and a

host of other details. The hand gun was fired with a 50-grain (3.24 grams) black powder charge of unspecified size and a 0.615-inch (15.6mm) diameter lead ball with an average muzzle velocity of 590.7 f/s (180.05 m/s). The matchlock or arquebus was fired with 50 grain (3.24 grams), 65 grain (4.2 grams), and 90 grain (5.83 grams) black powder charges of unspecified size. These resulted in an average muzzle velocity of 1242.3 f/s (378.65 m/s), 1443.7 f/s (440.05 m/s), and 1706.4 f/s (520.10 m/s) respectively. Penetration tests were conducted against 2mm, 4mm, and 6mm thick mild steel plates with the arquebus. The arquebus bullets pierced the 2 and 4mm plates but just failed to penetrate the 6mm mild steel plate.

A well-controlled experiment using a modern 0.75-caliber (19mm) diameter barrel to replicate the caliber of an eighteenth-century Brown Bess musket was conducted by Roberts et al. (2008). They (Roberts et al. 2008:4) summarize eighteenth and nineteenth century experiments that suggest the Brown Bess achieved muzzle velocities of 1500 f/s (457.2 m/s) on a regular basis. They did note that gunpowder of the era could be variable in quality and the resulting burn rates and gas pressures were likely to result in muzzle velocities different from the ideal.

Roberts et al. (2008:7-10) fired the barrel using an electrical matchhead placed in the flash pan. They used a replica rolled paper cartridge with various powder charges ranging from 116 grains (7.5 grams), 154 grains (10 grams), and 231 grains (15 grams) and a 0.691-caliber (17.4mm) lead ball. The experiment's purpose was to reach a muzzle velocity of 1500 f/s (457.2 m/s). The gun powders used were a 3A fine which is a military designation for special purpose black gunpowder and is roughly the equivalent of the U.S. FFFg black gunpowder, G12 which is roughly equivalent to U.S. Fg gunpowder, and coarse blasting powder. Each has a different burn rate resulting in different internal pressures.

The loading and firing process did account for priming the pan. They deducted 10 grains (0.65 grams) from each charge to control for priming. The experiment fired 21 shots using the three different gunpowder granulations. The firings resulted in a range of velocities based on powder charges of 427 f/s (130.2 m/s) to 1685 f/s (513.9 m/s). The range of velocities achieved using a 154 grain (10 gram) powder charge is of more direct interest and value to our experiment as it is the closest to the standard 110 grain charge used by the British during the American Revolution. The 3A fine gunpowder 154 grain charge resulted in firings producing 1032.5 f/s (314.7 m/s), 925.8 f/s (282.2 m/s), and 672.2 f/s (204.9 m/s). The G12 gunpowder charge of 154 grains resulted in muzzle velocities of 427.16 f/s (130.2 m/s), 691.3 f/s (210.7 m/s), and 1080.4 f/s (329.3 m/s). The Blasting grade powder at a 154-grain charge achieved muzzle velocities of 363.2 f/s (110.7 m/s), 454 f/s (138.4 m/s), and 612.2 f/s (186.6 m/s).

Roberts et al. (2008:20) concluded that at 1500 f/s (457.2 m/s) a bullet fired at an elevation of 35 degrees would travel 3937 feet (1200 meters) or if fired horizontally would travel 663 feet (202 meters). Their work also included calculating wound effects using ballistic gelatin and penetration studies of replica eighteenth century armor. They found the 1500 f/s bullet penetrated the armor and simulated human arm tissue and bone at 150 yards (137 meters). They observed that a shot would drag fragments of clothing into the wound as well as shatter human bone. They concluded that the Brown Bess ball would most certainly have significant wounding and lethal

effect at traditional combat ranges of 100 yards (91 meters) and 75 yards (69 meters) if it was traveling at 1500 f/s (457.2 m/s).

More recent controlled replica Brown Bess experimental firings were done by Lucien Haag (personal communication March 28, 2015). In these tests, Haag used a .72-caliber (18.29mm) Brown Bess with a 0.718-inch (18.23mm) diameter lead ball with a cotton patch. He used 100 grains (6.4 grams) of Goex FFG black powder. The firings resulted in a muzzle velocity of 951 f/s with 1108.3 ft-lbs (337.8m) of energy at the muzzle. At 200 yards (183m) the muzzle velocity dropped to 668.4 f/s (203.7m) and the energy to 547.6 ft-lbs (167m). The bullet is calculated to have dropped 100.55 inches (2.55m) over 200 yards (183m). The highest muzzle velocity reported was 1168 f/s (356m/s) with 1671 ft-lbs (509m) of energy at the muzzle. At 200 yards (183m) the bullet had slowed to 747.8 f/s (228m/s) and the energy dropped to 685.3 ft-lbs. (209m). The bullet drop was calculated at 75.64 inches (1.921m) at 200 yards (183m).

Haag (personal communication March 27, 2015) also fired a high-quality replica of a British Ferguson rifle. His test firings used a .650-caliber (16.5mm) lead ball weighing 402 grains (26 grams). The powder was Goex brand of 60 grains (3.88 grams) mixed from FFFg and FFFg in equal proportions. The firing produced several shots that exceeded the speed of sound, with one reaching 1237.9 f/s (377.3m/s). He also fired .610-caliber balls (16.4mm) with FFFg Swiss black powder with muzzle velocities at 1000 f/s (304m/s) and below.

Mike Willegal in his 1999 online Brown Bess accuracy analysis reports the British Brown Bess cartridge contained 6 to 8 drams of black powder which is equivalent to 165 (10.69 grams) to 220 grains (14.25 grams). He recognizes that some of that load is required to prime the flash pan. He tested two different granulations of black powder using an American Civil War Minié ball, presumably a .58-caliber (14.7mm). He found that on one case that 20 grains (6.1 grams) of powder produced a muzzle velocity of slightly less than 400 f/s (122m/s) and by increasing the charge up to 140 grains (9 grams) of powder he achieved a muzzle velocity of 1200 f/s (366m/s). His second black powder of a different size using a 50 grain (3.2 grams) charge up to a 130 grains (8.4 grams) charge resulted in muzzle velocities of just over 600 f/s (182.8m/s) to nearly 1400 f/s (476.7m/s). He does not specify which grade or size of black powder he used in his experiments.

Willegal's primary goal was to model musket accuracy and range. He calculated how the .75-caliber (19mm) Brown Bess using a .69-caliber (17.5mm) ball would drop at 1000 (304.8m/s), 900 (274.3m/s), 800 (243.8m/s), and 700 f/s (213.3m/s). He determined the drop to be from an average of 20 feet (6m) if fired at 1000 f/s (304.8m/s). His point is that for a shot to hit a target at 300 yards (274.3m) the gun would have to be aimed at a point 20 feet (6m) and 7.2 inches (18.2cm) above the target. Conversely at 75 yards (68.5m) the bullet is expected to drop only 22 inches (55.9cm) with a muzzle velocity of 1000 f/s (304.8m/s). The slower the muzzle velocity the greater the drop over distance. He cites Gibbon (1860) in describing the variation in drop of .69-caliber (17.5mm) musket shots at 200 yards (182.8m) being from 36 inches (91.4cm) to 54 inches (1.37m). Willegal concludes his analysis by stating the Brown Bess musket was unlikely to be effective beyond 150 yards (114m) given the reality of field conditions and general lack of target practice by armies of the eighteen and early nineteenth centuries.

Results of Live Fire Experiment and General Observations

The live fire experiment collected a significant amount of controlled data on muzzle velocity, bullet penetration, and bullet deformation from seven different flintlock firearms that represent the common Colonial and Revolutionary War firearms. The data is presented in both quantified and qualitative forms. Additional observations are presented that are relevant to shooting incident reconstruction. Archaeologists often recover impact deformed lead balls from Colonial era sites. The live fire experiment data enhances the capability to understand archaeological lead ball finds as well as the distribution pattern and context in which they found. An appreciation of how a bullet found its way into the ground as determined by this and other allows for better archaeological interpretation of the site or event being investigated.

Laid Cartridge Paper Observations

The laid paper cartridges were largely fully combusted during firing. The high-speed video confirms that cartridge paper did not fully combust in the barrel during firing, but numerous fragments were expelled with the gases, and most combust before reaching the ground. Fragments of laid cartridge paper are clearly seen in the videos being expelled down range from the barrels. Incompletely consumed cartridge paper pieces were found 15 feet to 30 feet down range from the shooting bench. In one case, about 30 feet from the bench, a piece of smoldering cartridge paper caused a grass fire that was quickly extinguished. The burn area was about 12 inches in diameter. Historically, the same phenomena were observed after shooting events. Lines of shooters have been interpreted from the discarded cartridge ends and fires are known to have been started by gun fire. Archaeologically the evidence for fires, cartridge paper, and cartridge tails or ends is not likely to survive. However, a careful vetting of oral history and historical documentation may reveal similar phenomena and coupled with surviving artifact patterns may allow for identification of potential firing lines.



Figure 17. French 1763/66 musket being fired, Note the laid cartridge paper debris and the buck and ball in the center right of the debris field.



Figure 18. Bits of unburned laid cartridge paper in the duff.



Figure 19. Tails of laid paper cartridges lay strewn on the ground at the site where the muskets were loaded.

Lead Ball Ranges as a Function of Velocity and Energy Loss

When a bullet is fired, it achieves an initial maximum velocity then begins to decelerate due to energy loss as a function of drag or resistance, and of course, gravity. Bullets have a maximum range they can travel before all energy and forward momentum is lost. However, bullets often fail to reach that maximum range due to hitting a target or some media. They also fail to reach maximum range as a function of the angle at which the shot was fired, was the barrel level to the ground or elevated? An elevated barrel will send the bullet further down range than a horizontally aimed barrel simply due to physics. The less velocity a bullet has when it drops to the ground the less deformation is likely to occur. This information is important to shooting event reconstruction such as determining if the recovered bullets are on or near a firing line or simply under or over shots. The live fire experiment data helps to address these questions in several ways.

During the live fire experiments shooting ranges were 94 yards for the first series and then reduced to 25 and 30 yards for buck and ball firing. Shooting into ballistic gel was done at 25 yards.

In dry air at 20 °C (68 °F), the speed of sound is 343 meters per second (1,125 ft/s; 1,235 km/h; 767 mph). The speed of sound is a function of air density at the local site and will vary with location. The range site weather conditions during the live fire experiment are consistent with the speed of sound being 1125 f/s (343 m/s).

The live fire experiment used seven flintlock firearms. The black powder charges were either 110 grains for the British and French muskets, British Artillery Carbine, and the 1740 Postdam musket or 85 grains for the Thomas Earle Colonial fowler. Reduced charges were also used during the ballistic gelatin experimental firing to capture the bullet in the gelatin.

The Thomas Earle fowler, .58-caliber using a rolled cartridge with a .520-caliber ball, achieved a muzzle velocity range of 1160 to 1345 f/s with average initial muzzle velocity of 1259.3 f/s. The fowler was also fired using a .580-caliber unpatched (loose) ball which resulted in a muzzle velocity range of 1415 to 1480 f/s with an average muzzle velocity of 1444 f/s. A three shot string using buckshot was also fired with 85 grains of black powder. The first shot used a .58-caliber ball and three .282 diameter buckshot that had an initial muzzle velocity of 655 f/s. The second buckshot firing used 6 loose .282 diameter buckshot also resulted in a muzzle velocity of 655 f/s. The third shot used 6 loose .282 diameter buckshot. On this shot the muzzle velocity varied for the buckshot. The first three buckshot exited the muzzle as a group and achieved 495 f/s, the second two buckshot were closely spaced but achieved only 240 f/s, and the third buckshot was slower yet at 230 f/s. Except for the buck and ball shot and the two buckshot all single ball shots exceeded the speed of sound.

The external ballistic calculations indicate the .520 and .580 balls would travel the farthest and have greater penetration capability at greater ranges than the larger caliber bullets used in this experiment. See the graphs for the bullet drop calculations that emphasize this point.

The .65-caliber British Artillery Carbine firing a .580 diameter ball also exceeded the speed of sound for eight of its ten shots. The initial muzzle velocity ranged from 960 f/s to 1335 f/s with an average of 1018 f/s, which is below the speed of sound. It is notable that the two shots that were well below the speed of sound resulted in dropping the average muzzle velocity for all shots to less than the speed of sound. Like the fowler the carbine balls would go further and have greater penetration capability than the larger caliber muskets. This can be observed in the bullet drop graphs.

The British 1742 Long Land Pattern musket, .76-caliber, was fired five times using a 110-grain charge with a paper patched .69 diameter ball. The muzzle velocity ranged from 780 to 870 f/s with an average velocity of 822 f/s. All shots were less than the speed of sound and had far less range as can be observed in the drop graphs.



Figure 20. The British 1742 Long Land pattern musket during live firing with flame and smoke being discharged from the muzzle, cartridge paper and the ball shown right of the smoke column.

The French 1728/41 .70-.72 slightly oval bore was fired 5 times with a 110-grain charge with a paper patched ball .626 in diameter. This shot string ranged in muzzle velocity from 775 to 960 f/s with an average muzzle velocity of 870 f/s. Like the British 1742 Long Land the French 1728/41 did not reach the speed of sound. One reason for not reaching the speed of sound may be the oval bore. This shape may not have allowed the balls to fully conform to the bore which, including windage, allowed more gas to escape around the balls during firing. Such an event would lower the gas pressure and the bullet velocity.

The French 1763/66 musket, .68-caliber, using a 110-grain charge with a .626 diameter ball. It was fired 15 times with paper patched buck and ball loads. The three buckshot were .282 diameter and the ball .626 diameter. The 15 shots had a muzzle velocity range of 865 to 1215 f/s. Eight of the fifteen shots were sub-sonic with an average muzzle velocity somewhat below Mach 1 at 1009 f/s. The muzzle velocity range is wide for this gun and is probably due to the amount of windage between the .68 bore firing a .626 ball. Since 7 shots did exceed the speed of sound, and all variables were held constant between the 1728/41 and the 1763/66 French muskets, this helps support the contention that the earlier style's oval bore shape influenced the lower muzzle velocities seen in that shot string.

The Hessian style 1740 Postdam musket is .73-caliber. It was fired five time with a 110 grain charge and a .626 ball. Like the British 1742 and the French 1728/41 muskets the muzzle velocity did not achieve Mach 1. It ranged from 712 to 858 f/s with an average of 817 f/s.

Ball Velocity and Calculated Bullet Drop Ranges

The initial muzzle height above ground, muzzle velocity, along with ambient air temperature, wind speed, site elevation, and humidity were then used to calculate external ballistics data using the Round Ball Ballistics Calculator found online

(http://www.ctmuzzleloaders.com/ctml_experiments/rbballistics/rbballistics.html) and downloaded to a hard drive. Comparison with other ballistic calculators including the Sierra Infinity-6 and Shooters Calculator.com indicates the ball velocity, energy, and time calculation are within 1% (usually 1% less) of the various programs.

Using the Round Ball Ballistic Calculator the data were entered for each shot using muzzle height above ground as a dependent variable. The amount of bullet rise and/or drop was then calculated for each round at 25 yards, 35 yards, and 100 yards to simulate known combat ranges. Graphs were output through the calculator for minimum and maximum velocity for each gun type. The following graphs provide a visual summary of when a ball is likely to hit the ground given the powder charge, its weight or mass, and initial muzzle velocity. For each graph the Velocity is expressed as feet per second (f/s), Energy loss is expressed as foot pounds of energy (fpe), the X axis is range in yards, and the Y axis is velocity as f/s and energy as fpe

It is important to note when fpe drops below the 300 to 200 fpe range the potential for lethal wounding is unlikely. Assuming the intended target is a human the fpe needed to incapacitate is dependent on age of the individual and the type of clothing being worn as well as the type of media the bullet strikes.

Each graph has a textual summary to aid in explanation of the data presentation.

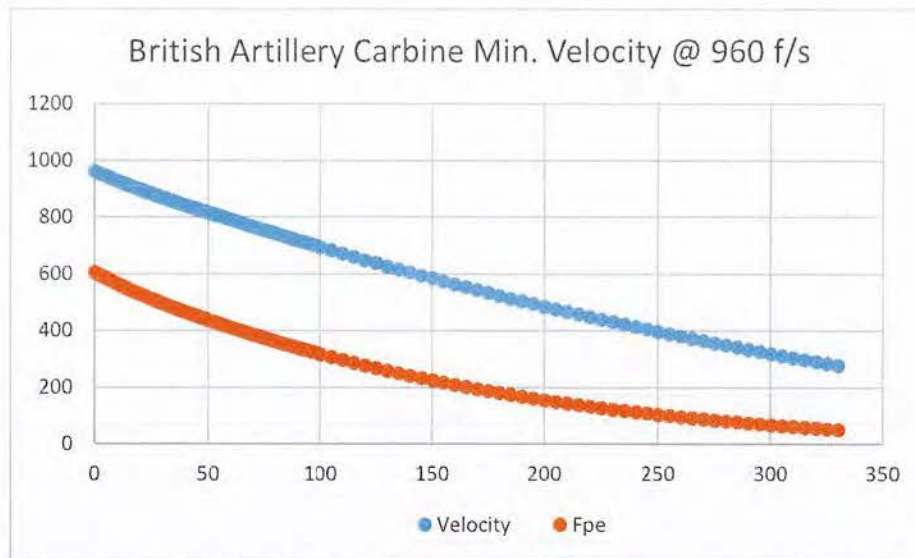


Figure 21. **British Artillery Carbine** - .580 ball and 110 grain powder charge at 960 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.3 inches at 25 yards, 1.2 inches at 35 yards, and drop 14.6 inches at 100 yards then it is calculated to strike the ground at 150 yards.

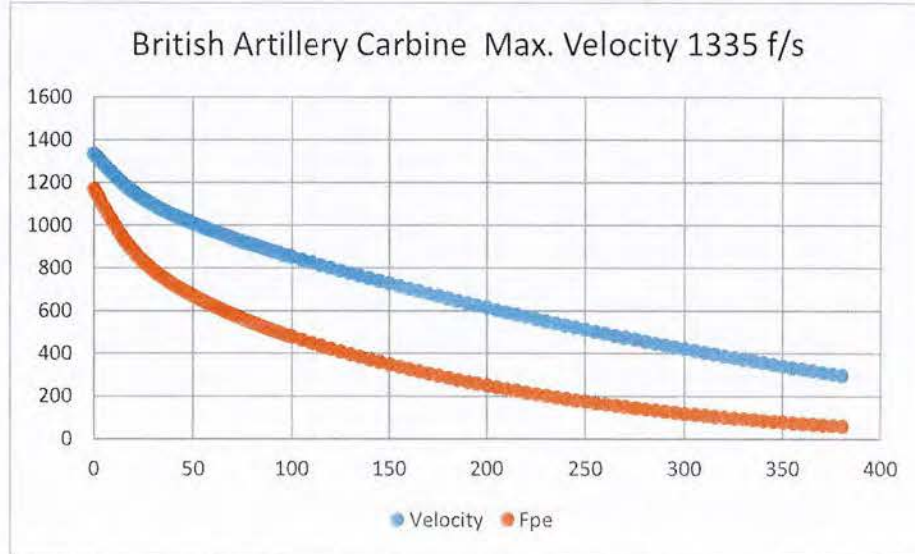


Figure 22. **British Artillery Carbine** - .580 ball and 110 grain powder charge at 1335 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 0.7 inch at 25 yards, 0.7 inch at 35 yards, and drop 9.5 inches at 100 yards then it is calculated to strike the ground at 170 yards.

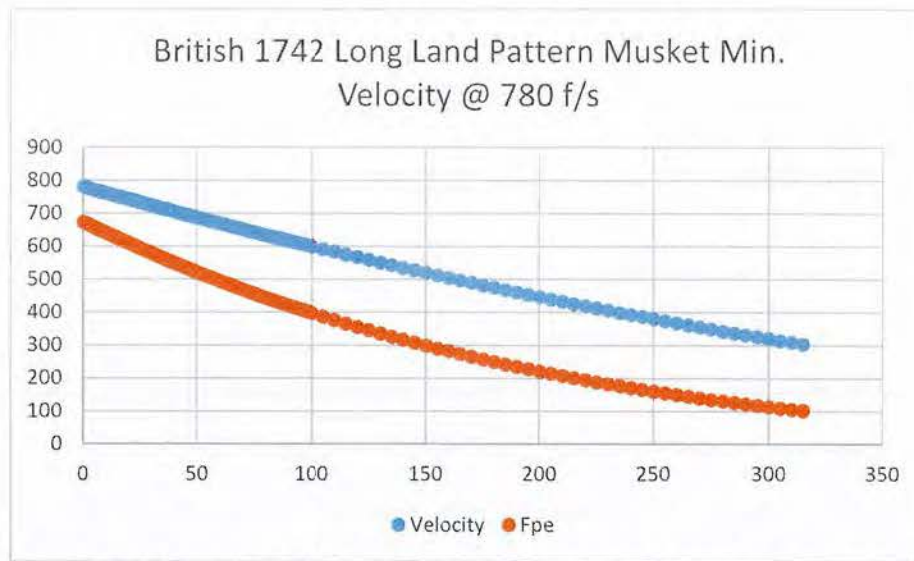


Figure 23. **British 1742 Long Land Pattern Musket** - .69 ball and 110 powder charge at 780 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.6 inches at 25 yards, 1.7 inches at 35 yards, and drop 20.2 inches at 100 yards then it is calculated to strike the ground at 135 yards.

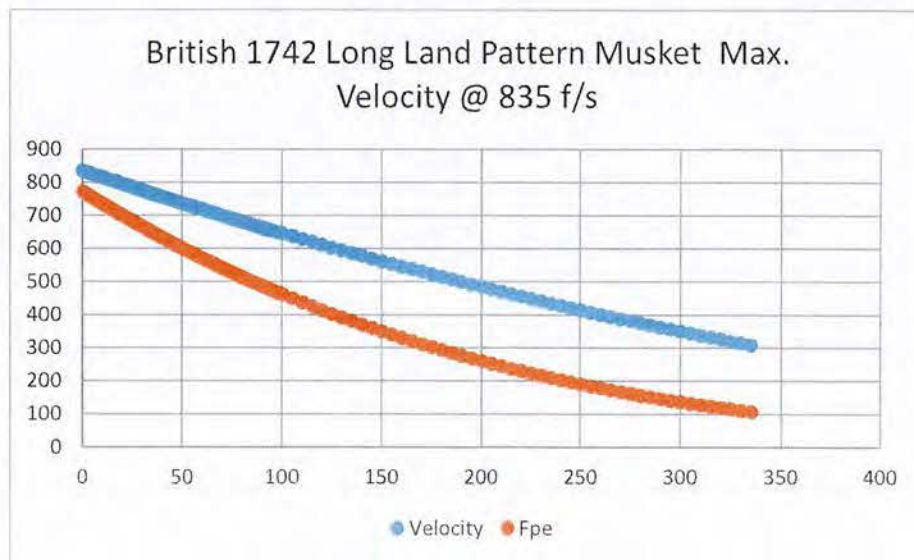


Figure 24. **British 1742 Long Land Pattern Musket** - .69 ball and 110 powder charge at 835 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.6 inches at 25 yards, 1.4 inches at 35 yards, and drop 17.5 inches at 100 yards then it is calculated to strike the ground at 140 yards.

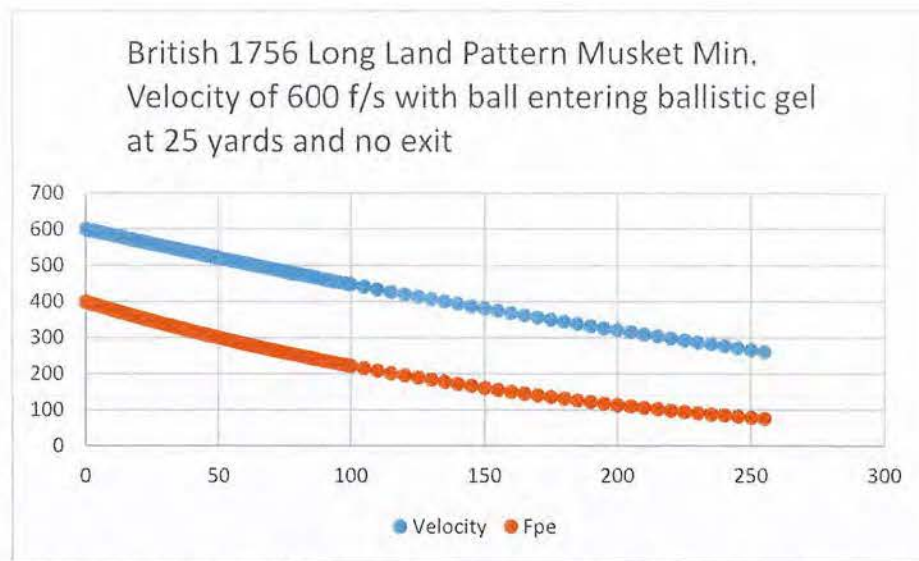


Figure 25. **British 1756 Long Land Pattern Musket** - .69 ball with 75 grain powder charge with a velocity of 600 f/s fired at 25 yards into Clear Ballistic gel with ball being retained in the gel. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 3.2 inches at 25 yards, 3.1 inches at 35 yards, and drop 36.4 inches at 100 yards then it is calculated to strike the ground at 110 yards.



Figure 26. **British 1756 Long Land Pattern Musket** - .69 ball with 110 grain powder charge with a velocity of 830 f/s fired at 25 yards into Clear Ballistic gel with ball passing through 32 inches of gel. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.6 inches at 25 yards, 1.6 inches at 35 yards, and drop 17.8 inches at 100 yards then it is calculated to strike the ground at 140 yards.



Figure 27. **British 1756 Long Land Pattern Musket** - .69 ball with 110 grain powder charge fired at 25 yards into Clear Ballistic gel with ball passing through 32 inches of gel. Ball exited gel at 360 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 10.6 inches at 35 yards, and it is calculated to strike the ground at 80 yards.

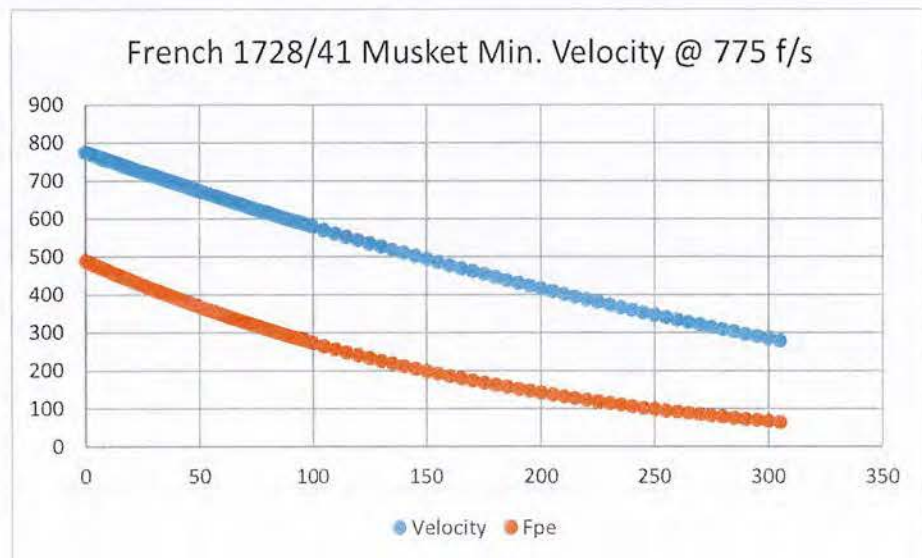


Figure 28. **French 1728/41 Musket** - .662 ball with 110 grain powder charge with a velocity of 775 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the calculated drop over distance indicates the ball is calculated to rise 2 inches at 25 yards, 1.7 inches at 35 yards, and drop 21.7 inches at 100 yards then it is calculated to strike the ground at 130 yards.

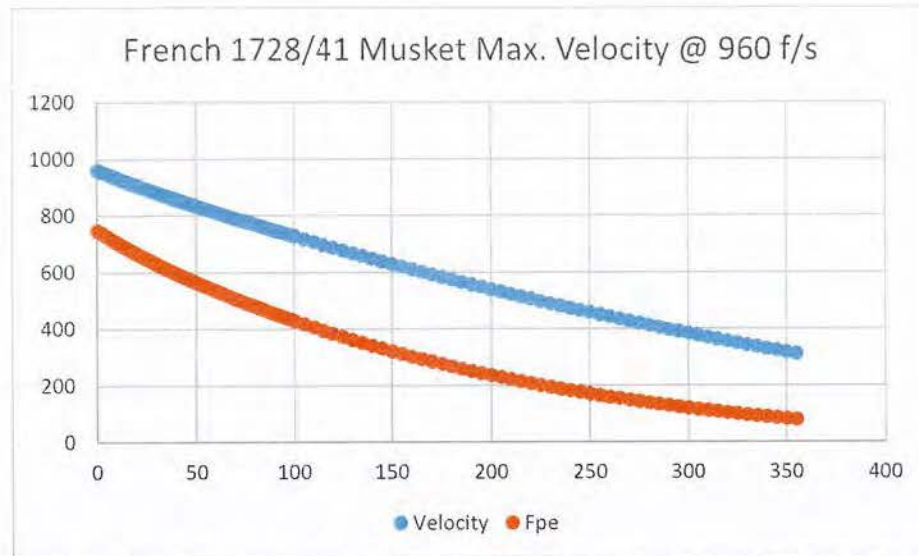


Figure 29. **French 1728/41 Musket** - .662 ball with 110 grain powder charge with a velocity of 960 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.2 inches at 25 yards, 1.1 inches at 35 yards, and drop 13.6 inches at 100 yards then it is calculated to strike the ground at 150 yards.

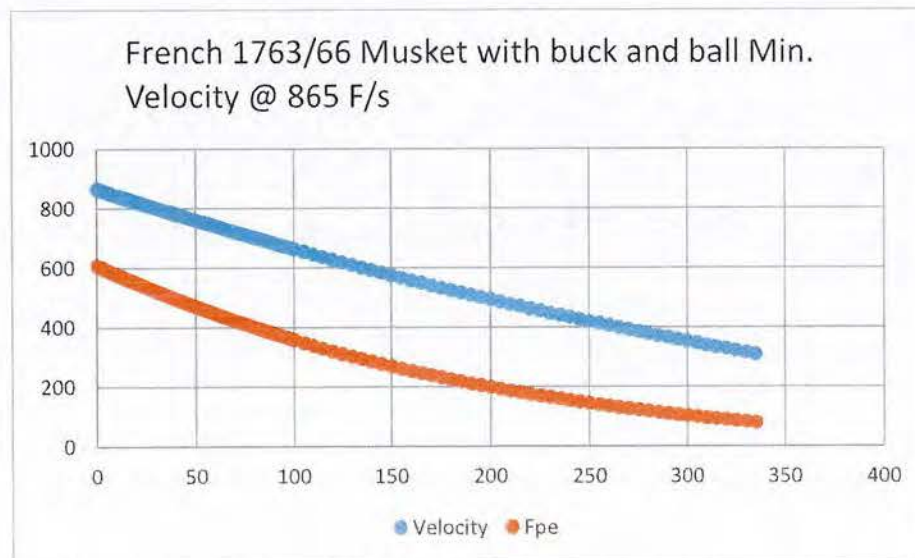


Figure 30. **French 1763/66 Musket** - .662 ball and 3 .282 buckshot with 110 grain powder charge with a velocity of 865 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.5 inches at 25 yards, 1.4 inches at 35 yards, and drop 16.4 inches at 100 yards then it is calculated to strike the ground at 140 yards.

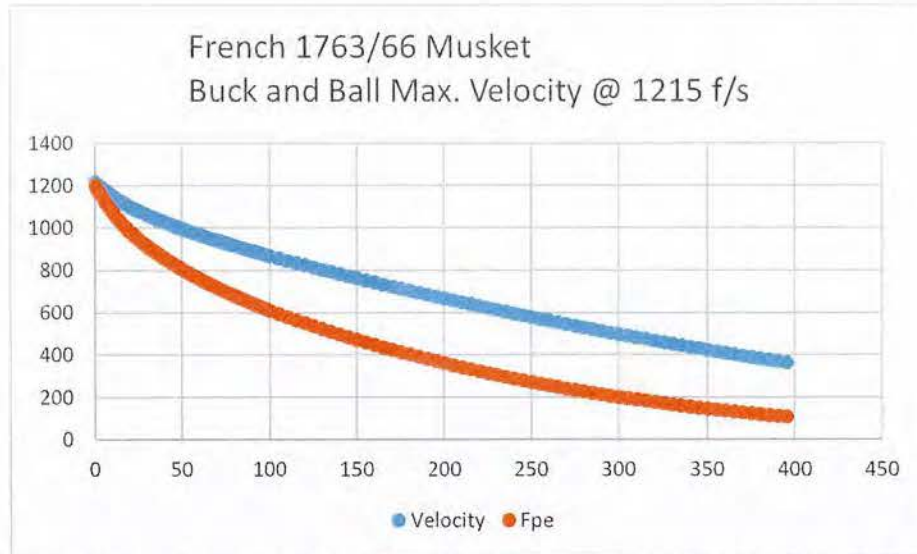


Figure 31. **French 1763/66 Musket** - .662 ball and 3 .282 buckshot with 110 grain powder charge with a velocity of 1215 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 0.7 inch at 25 yards, 0.7 inch at 35 yards, and drop 9.4 inches at 100 yards then it is calculated to strike the ground at 175 yards.

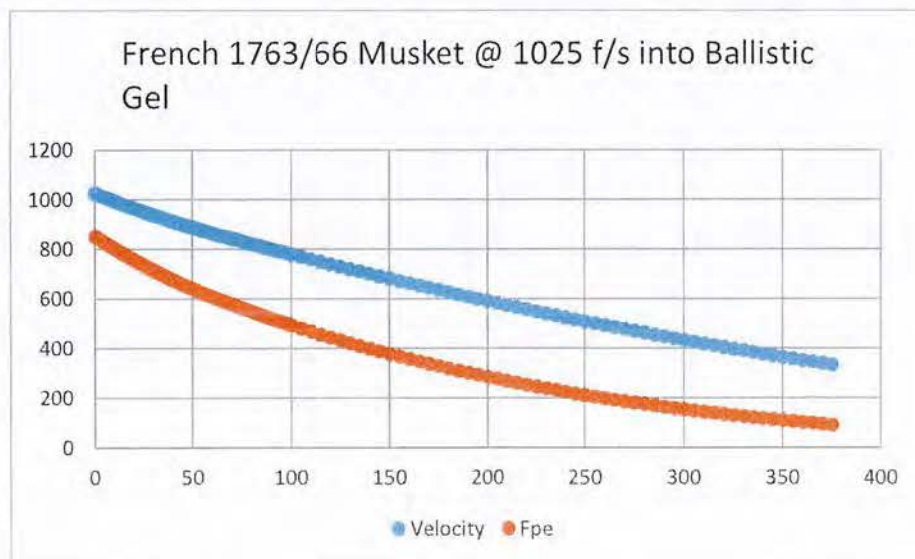


Figure 32. **French 1763/66 Musket** - .662 ball with 110 grain powder charge with a velocity of 1025 f/s fired into Clear Ballistic gel, and passing through 32 inches of gel. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1 inch at 25 yards, 0.9 inch at 35 yards, and drop 11.9 inches at 100 yards then it is calculated to strike the ground at 160 yards.

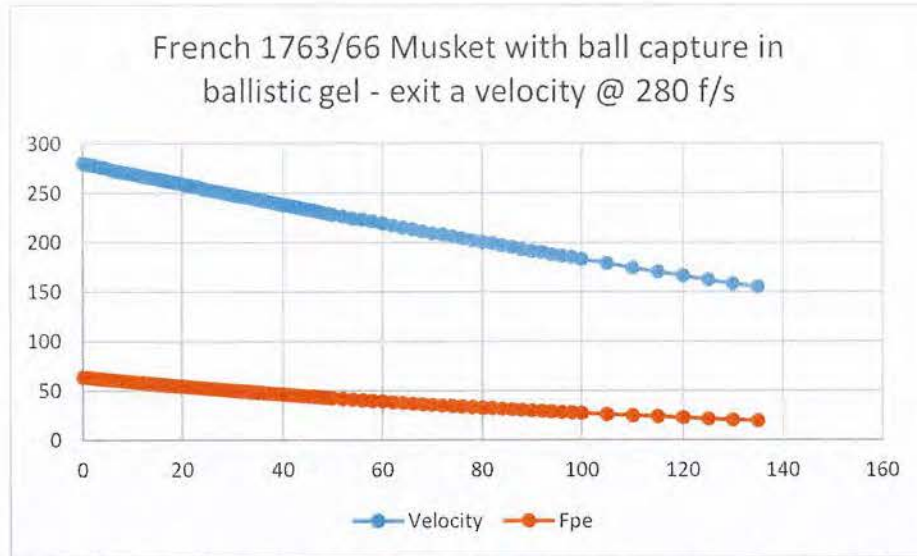


Figure 33. **French 1763/66 Musket** - .662 ball with 110 grain powder charge fired into Clear Ballistic gel at 25 yards, and passing through 32 inches of gel with an exit velocity of 280 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 16.1 inches at 35 yards, and drop 11.9 inches at 100 yards then the ball will strike the ground at 70 yards.

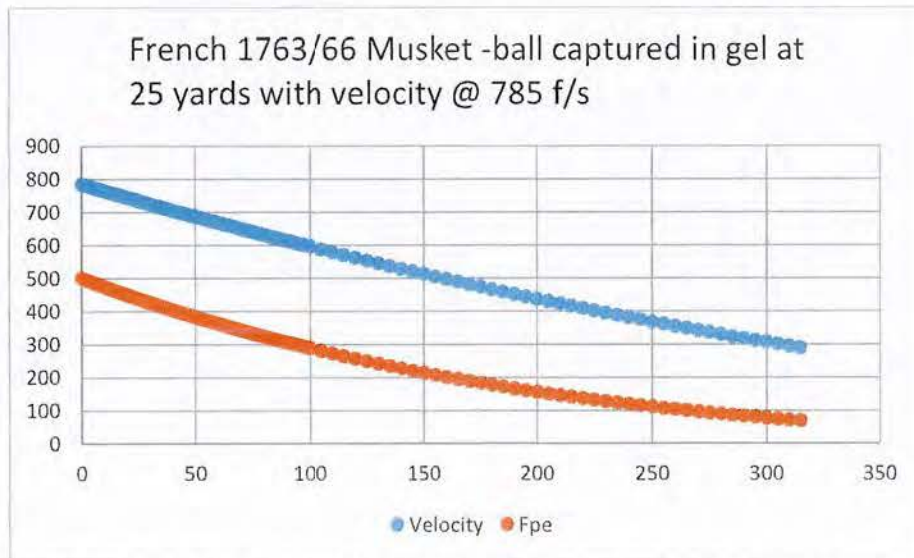


Figure 34. **French 1763/66 Musket** - .662 ball with 75 grain powder charge with a velocity of 785 f/s fired into Clear Ballistic gel at 25 yards, with ball retained in gel. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the calculated drop over distance indicates the ball would have struck the ground at 135 yards.

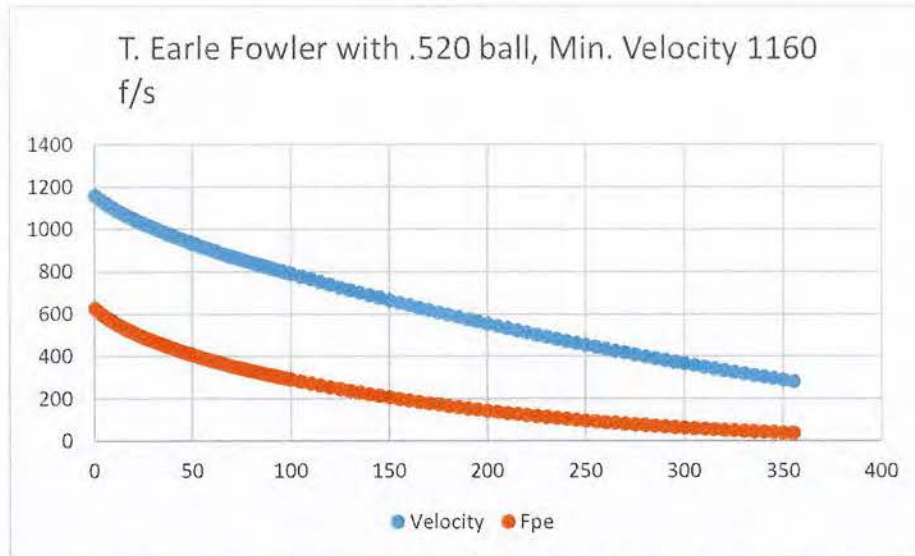


Figure 35. **Thomas Earle Fowler** - .520 ball with 85 grain powder charge with a velocity of 1160 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 0.8 inch at 25 yards, 0.9 inch at 35 yards, and drop 11.4 inches at 100 yards then it is calculated to strike the ground at 160 yards.

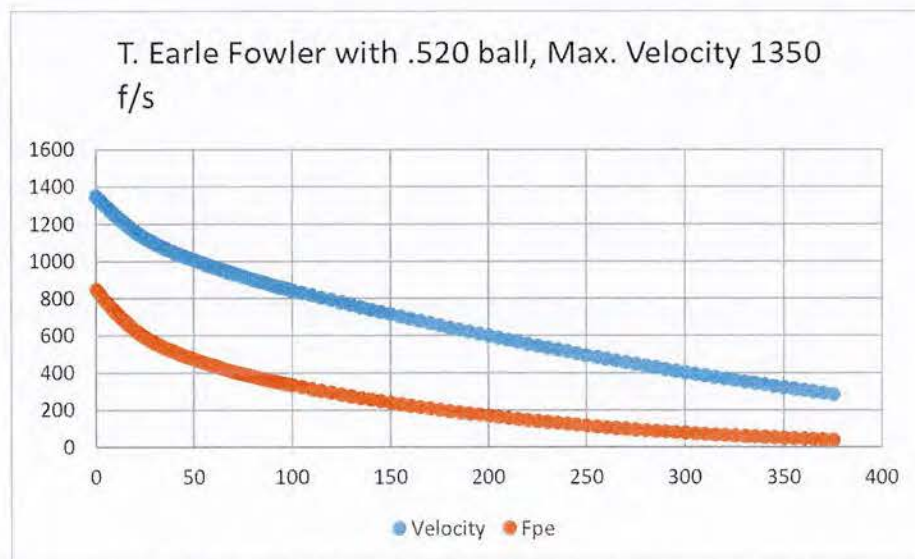


Figure 36. **Thomas Earle Fowler** - .520 ball with 85 grain powder charge with a velocity of 1350 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 0.7 inch at 25 yards, 0.7 inch at 35 yards, and drop 9.8 inches at 100 yards then it is calculated to strike the ground at 170 yards.

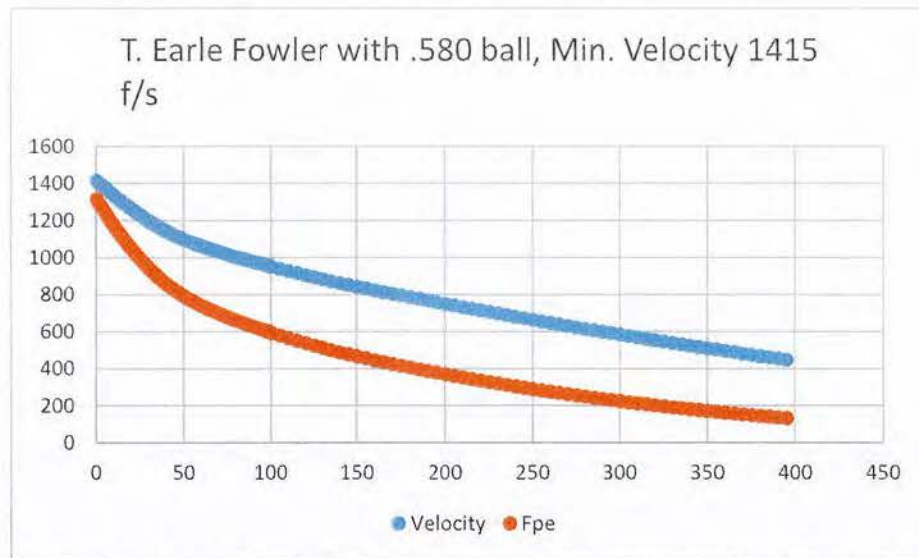


Figure 37. **Thomas Earle Fowler** - .580 ball with 85 grain powder charge with a velocity of 1415 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 0.6 inch at 25 yards, 0.6 inch at 35 yards, and drop 7.9 inches at 100 yards then it is calculated to strike the ground at 185 yards.

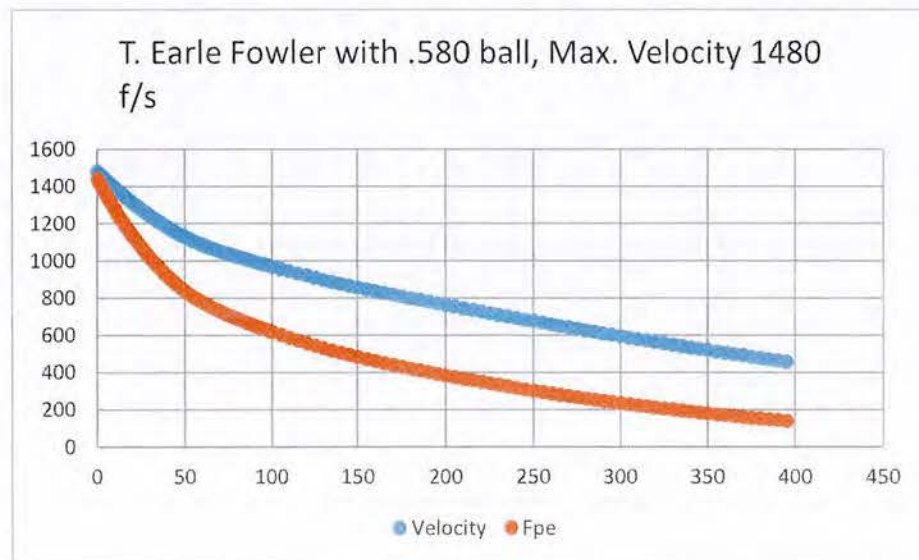


Figure 38. **Thomas Earle Fowler** - .580 ball with 85 grain powder charge with a velocity of 1480 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 0.6 inch at 25 yards, 0.6 inch at 35 yards, and drop 7.5 inches at 100 yards then it is calculated to strike the ground at 185 yards.

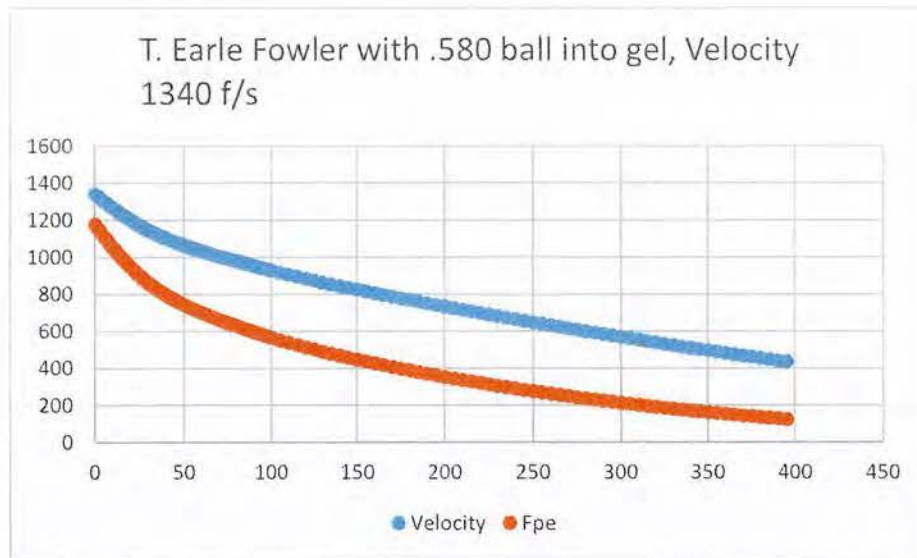


Figure 39. **Thomas Earle Fowler** - .580 ball with 85 grain powder charge fired into Clear Ballistic gel at 25 yards, and passing through 32 inches of gel with at a velocity of 1340 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 0.7 inch at 35 yards, and drop 8.3 inches at 100 yards then the ball will strike the ground at 180 yards.

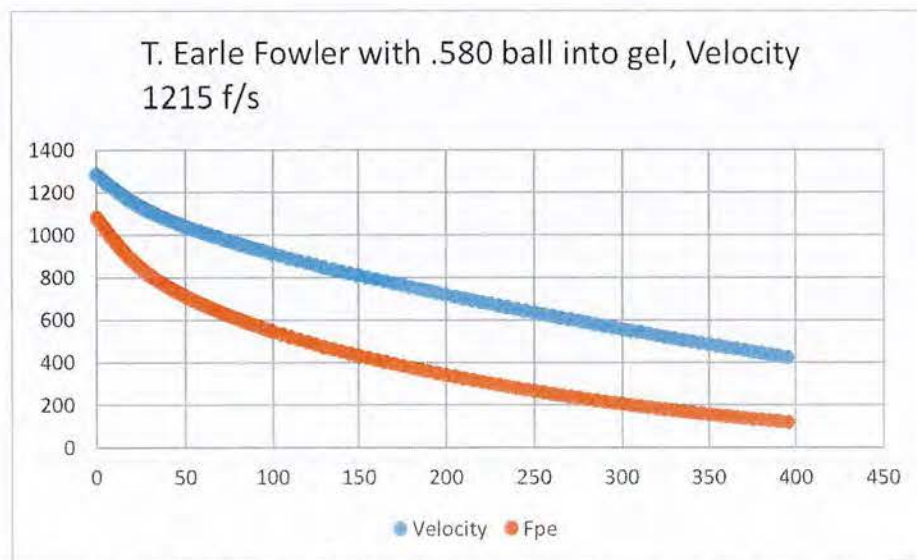


Figure 40. **Thomas Earle Fowler** - .580 ball with 85 grain powder charge fired into Clear Ballistic gel at 25 yards, and passing through 32 inches of gel with at a velocity of 1285 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 0.7 inch at 35 yards, and drop 8.8 inches at 100 yards then the ball will strike the ground at 175 yards. Note: The graph legend incorrectly states the velocity as 1215 f/s, but it is correct in the caption at 1280 f/s.

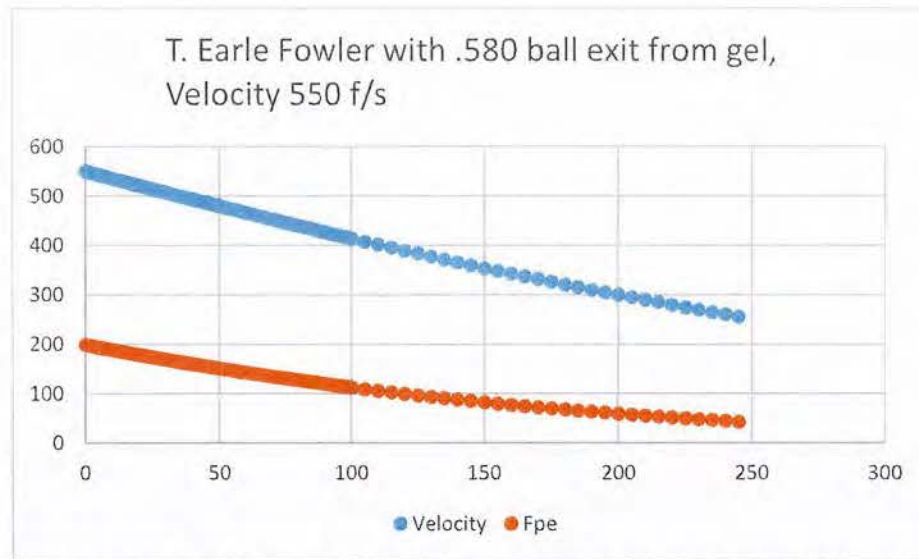


Figure 41. **Thomas Earle Fowler** - .580 ball with 85 grain powder charge fired into Clear Ballistic gel at 25 yards, and passing through 32 inches of gel with an exit velocity of 550 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 3.7 inches at 35 yards, and drop 43.1 inches at 100 yards then the ball will strike the ground at 105 yards.

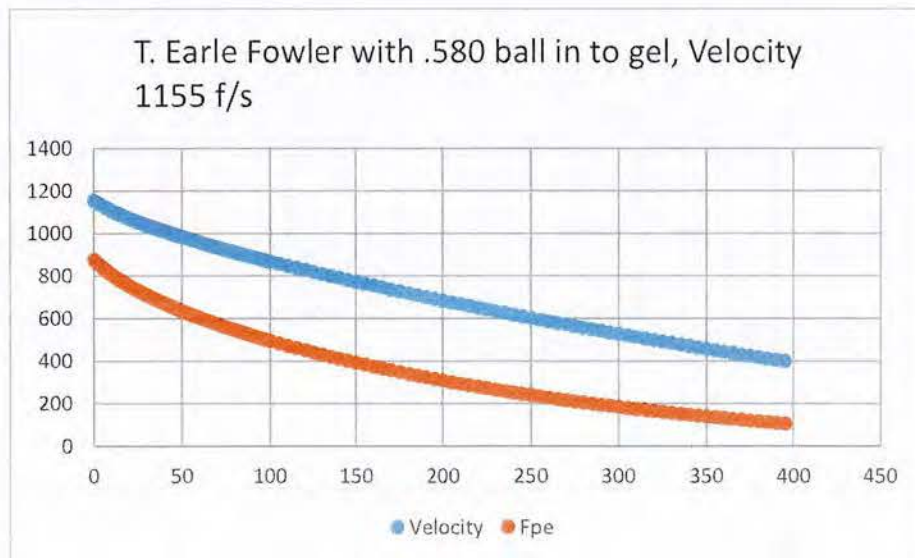


Figure 42. **Thomas Earle Fowler** - .580 ball with 75 grain powder charge fired into Clear Ballistic gel at 25 yards at a velocity of 1155 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 0.8 inch at 25 yards, 0.8 inch at 35 yards, and drop 9.8 inches at 100 yards then the ball will strike the ground at 170 yards.

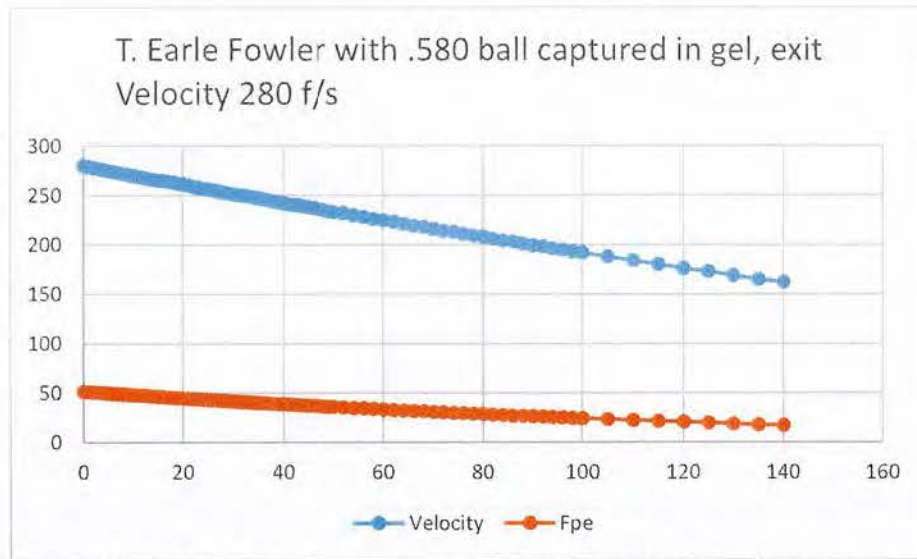


Figure 43. **Thomas Earle Fowler** - .580 ball with 75 grain powder charge fired into Clear Ballistic gel at 25 yards with an exit velocity of 280 f/s, however the ball rebounded and was captured in the gel. Hypothetically with the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 15.7 inches at 35 yards then the ball will strike the ground at 70 yards.

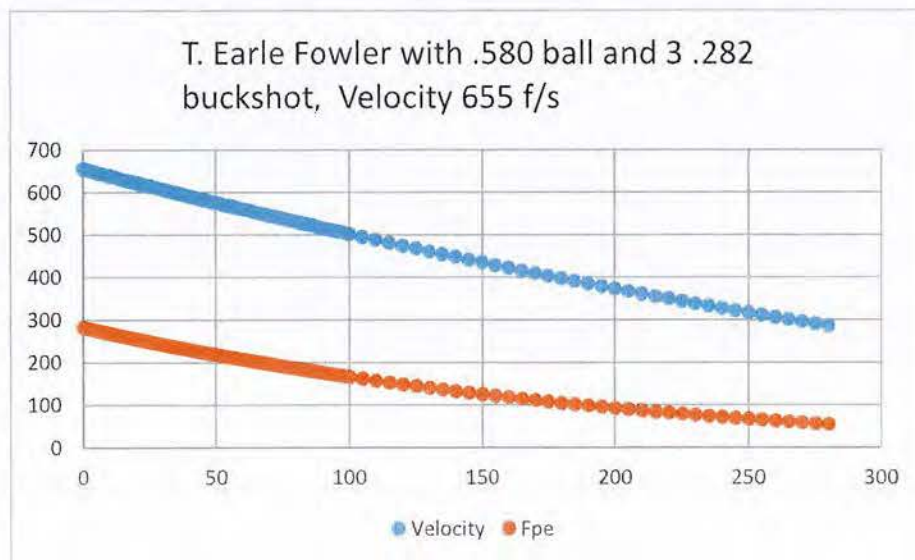


Figure 44. **Thomas Earle Fowler** – loaded with .580 ball and 3 .282 buckshot with 85 grain powder charge with a velocity of 655 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 2.9 inches at 25 yards, 2.5 inches at 35 yards, and drop 2.4 inches at 100 yards then the shot will strike the ground at 115 yards.



Figure 45. **Thomas Earle Fowler** – loaded with 6 - .282 buckshot with 85 grain powder charge. The first 3 shot had a velocity of 495 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the shot is calculated to rise 39.7 inches at 25 yards, 43.7 inches at 35 yards, and the shot will strike the ground at 55 yards.

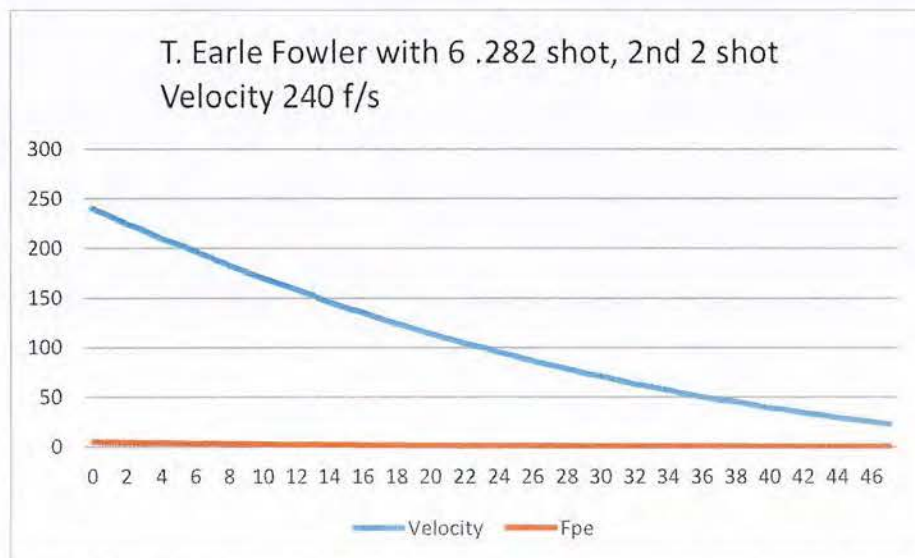


Figure 46. **Thomas Earle Fowler** – loaded with 6 - .282 buckshot with 85 grain powder charge. The second 2 shot had a velocity of 240 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the shot is calculated to drop 43.6 inches at 25 yards and the shot will strike the ground at 26 yards.

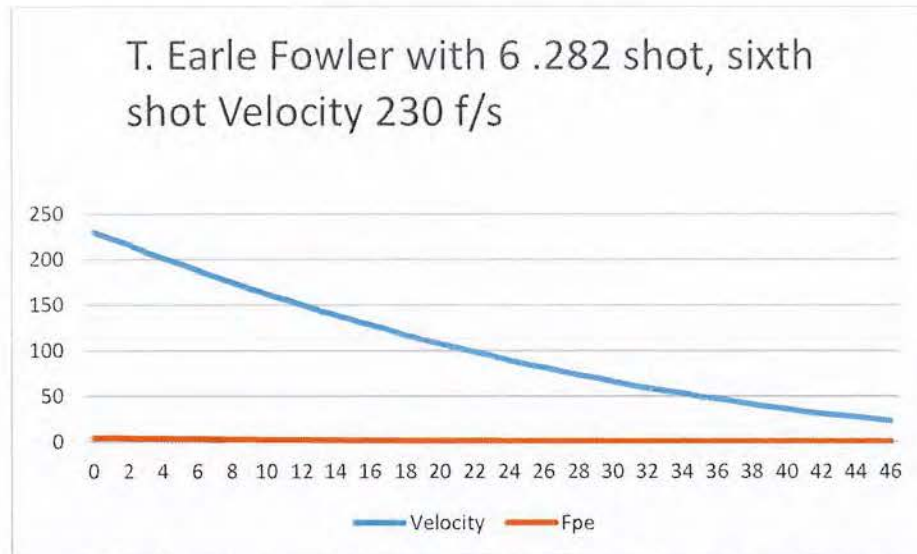


Figure 47. **Thomas Earle Fowler** – loaded with 6 - .282 buckshot with 85 grain powder charge. The sixth shot had a velocity of 230 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the shot is calculated to drop 7.5 inches at 25 yards and the shot will strike the ground at 30 yards.



Figure 48. **1740 Potsdam Musket** - .626 ball with 110 grain powder charge with a velocity of 712 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 2.2 inches at 25 yards, 2 inches at 35 yards, and drop 25.5 inches at 100 yards then it is calculated to strike the ground at 125 yards.

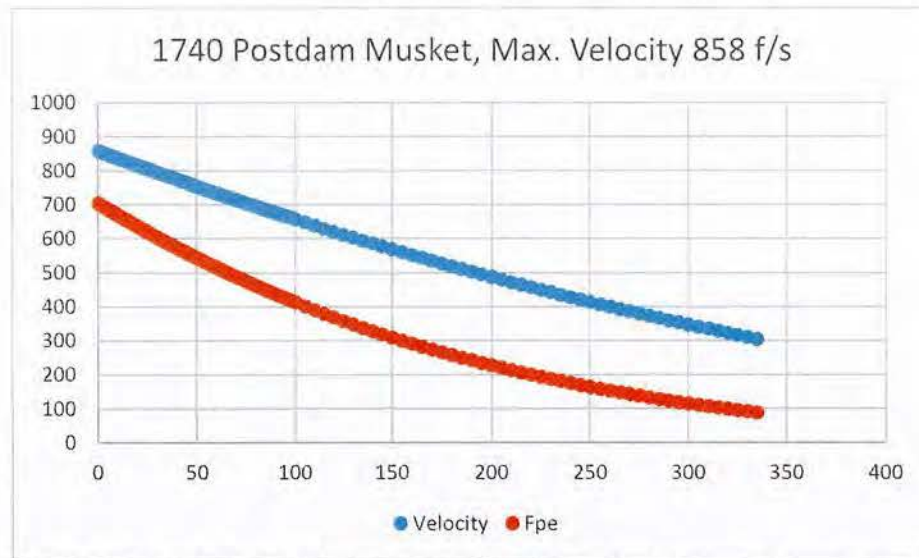


Figure 49. **1740 Potsdam Musket** - .626 ball with 110 grain powder charge with a velocity of 858 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.4 inches at 25 yards, 1.3 inches at 35 yards, and drop 16.6 inches at 100 yards then it is calculated to strike the ground at 140 yards.

Most recovered balls and buckshot struck some type of media before coming to rest. Many hit the sand backstop at the 94-yard range, some hit and passed through the target frame, others struck and embedded in or passed through the wooden palisade behind the earth berm. Those bullets are discussed in the bullet penetration and deformation section. The few bullets that did not strike media and were recovered down range at or near ground surface represent those that dropped at the end of their flight path. The landform where the firing range was established slopes, very slightly, down and away from the shooting bench. Past the palisade line the ground drops a bit more noticeably. That ground slope allowed bullets to travel farther than the predicted model suggested. While there is no one-to-one correlation with the caliber and muzzle velocity or where they dropped, bullets were recovered within a one or two standard error deviation of the predicted drop range.

Tissue Simulate Live Firing Results

Tissue simulants are materials that approximate the density of human tissue and approximate the penetration resistance of soft tissue (Boackle 2011). Bullets fired into tissue simulants create a temporary and a permanent wound cavity that mimics actual wound trauma reasonably well (MacPherson 1994:63-78). The temporary cavity can be observed using high speed videography. The permanent cavity is what remains after the bullet passes through or is captured in the tissue simulant. A variety of studies demonstrate that tissue simulants meeting the standard BB penetration test (MacPherson 199:74-75) achieve dynamic equivalence which can then be used to model wound trauma. When a spherical ball enters the tissue simulant at a given velocity the gelatin begins to deform as a response to strain forces acting upon it. The gelatin deforms

elastically until it reaches a critical point where it ruptures and then rebounds to near its original position. The strain forces caused by the bullet diameter, mass, and velocity create an elastic response in the gelatin that creates a wound track or cavity that expands with the initial strain and then contracts leaving a visible but small wound track.

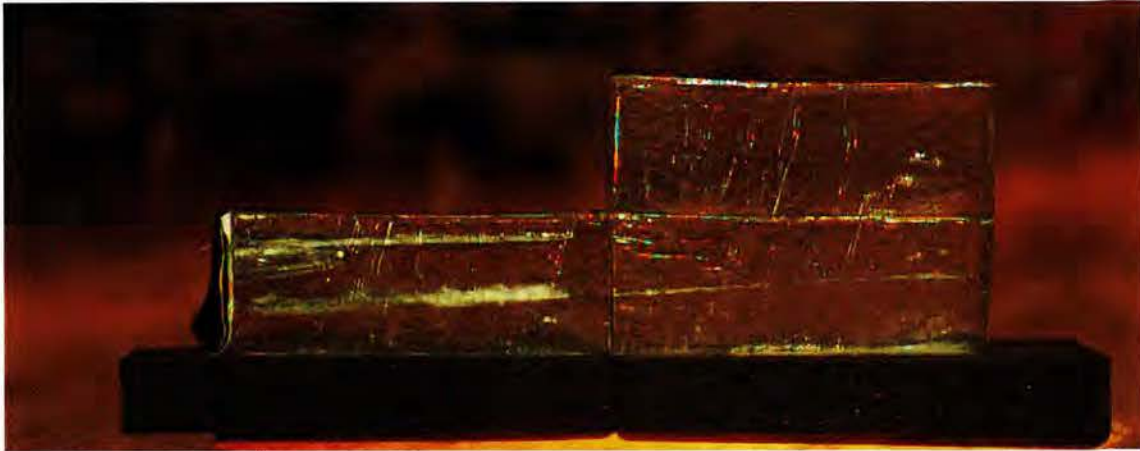


Figure 50. Ballistic gelatin block firing test set up. Two blocks placed end to end create 32 inches of length. Note the wound tracks from previous shots in the two lower blocks. The large cavity on the left side is a .626 diameter ball entering the block and creating an initial wound cavity.

The live fire experiment used Clear Ballistic® gelatin obtained from Clear Ballistics®. Clear Ballistic gelatin meets the FBI and NATO protocols for testing terminal ballistics of human tissue simulants. The protocol standard states that an acceptable calibrated gelatin must have a steel BB (.177 inch or 4.5mm in diameter) shot at 590 f/s (180 m/s) at 10 feet (3.04m) come to rest between 1.73 and 1.8 inches (4.4 and 4.6cm) into the gelatin.

The Clear Ballistics' blocks are 6x6 inches square and 16 inches long. The blocks were placed on a specially constructed wooden table covered with 2 ½ inch thick foam pads. Two blocks were placed end to end and aligned creating a 32-inch long area of gelatin. A roughly 6x6 inch square of cloth, meant to simulate the thickness and weight of average Colonial era clothing, was placed on the front and rear of the lower blocks.

The cloth squares were made up broadcloth followed by a piece of serge to represent a coat and lining. Behind these was another piece of broadcloth and a piece serge to represent a waistcoat and lining. The final piece of cloth was a square of linen representing a shirt. The cloth was replica fabric that is the same weight and weave of known historic cloth constructed of similar materials (Potter and Hanson 2014; Moore and Haynes 2003; Brown 1999; Kidwell and Christman 1974).

The British 1756 Long Land pattern musket, .76-caliber, was fired nine times in the ballistic gelatin shot series. The paper patched ball was .69 in diameter. The first four shots used a 110-grain charge that resulted in muzzle velocities of 760, 790, 815, and 830 f/s. For one shot the entrance and exit velocity for the gelatin was recorded. The entrance velocity was 830 f/s with the ball passing through 32 inches of gelatin and exiting at 360 f/s, with a loss of 470 f/s.



Figure 51. One of the cloth squares, 6x6 inch, used to simulate a Colonial era uniform clothing thickness. Two shots have passed through the cloth, and a recovered .626 diameter ball is shown next to the hole it created. Note: entry holes in cloth or tissue are often smaller than the bullet that created it due to the elasticity of the media.

The black powder charge was reduced to 75-grains to capture the ball in the gelatin. Five shots were fired, reaching 600 f/s, 605 f/s, 615 f/s, and two at 630 f/s. Four balls missed or passed through the gelatin. One, 600 f/s, passed through the side of the blocks and exited at 22 inches into the gelatin. One shot reaching 630 f/s was captured at 24 inches into the gelatin.

The French 1763/66 musket was fired twice into the gelatin. The first round was fired with a 110-grain charge and a .626 diameter ball. The muzzle velocity achieved 1025 f/s which is just above Mach 1. The ball passed through 32 inches of gelatin and exited the block at 280 f/s.

The second shot used the .626 diameter ball but with a 75-grain charge to reduce the velocity enough to capture the ball in the gelatin. The muzzle velocity was 785 f/s and the ball passed through the gelatin along with a piece of the cloth, but did not break the plane of the block and the ball rebounded back into the block. It was recovered at 29 inches into the gelatin block (see ball penetration and deformation section).



Figure 52. A .69 diameter ball fired from a British 1756 Long Land Pattern musket exiting 32 inches of gelatin. Note the initial wound cavity, bits of cloth in the wound cavity on the right and a larger piece of cloth exiting the block behind the ball.

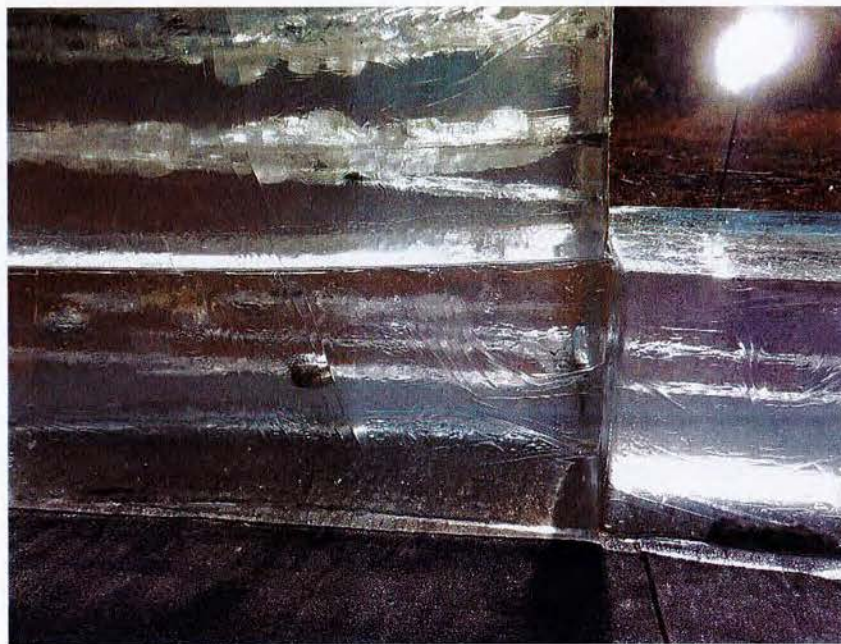


Figure 53. A .69 diameter ball fired from the British 1756 Long Land Pattern musket with 75 grains of powder at 25 yards. The ball traveling at 630 f/s traveled 24 inches into the gelatin blocks.



Figure 54. A fabric impressed .69 diameter ball fired from the British 1756 Long Land Pattern musket with 75 grains of powder at 25 yards. The fabric impressions resulted from passing through the simulated uniform clothing.

The ball that rebounded back into the gelatin is a known effect in the study of wound trauma. The rebounding effect seen with the French 1763/66 musket fired at 785 f/s into gelatin is consistent with the MacPherson's (1994:156) experimental work. It reflects the static strain, kinetic energy dispersion, and gelatin excitation of the bullet as it passed through the tissue simulant. MacPherson (1994:224-227) concluded that bullets that rebound have lost enough velocity to fall below the minimum velocity to either penetrate or exit the media. In cases involving human skin that minimum velocity is somewhat variable but generally falls into the range of 200 to 350 f/s. In part that is dependent on age, health, and body part involved.

The high-speed video shows the uniform fabric being pushed into the wound track and then the ball, given its greater velocity and aerodynamic capability, passing ahead of the cloth. The cloth often left debris in the wound channel that is easily observable as small fragments of thread embedded in the wound track. In some cases the larger piece of cloth will exit the gelatin behind the ball, but in some cases the cloth lost momentum and remained in the wound channel.

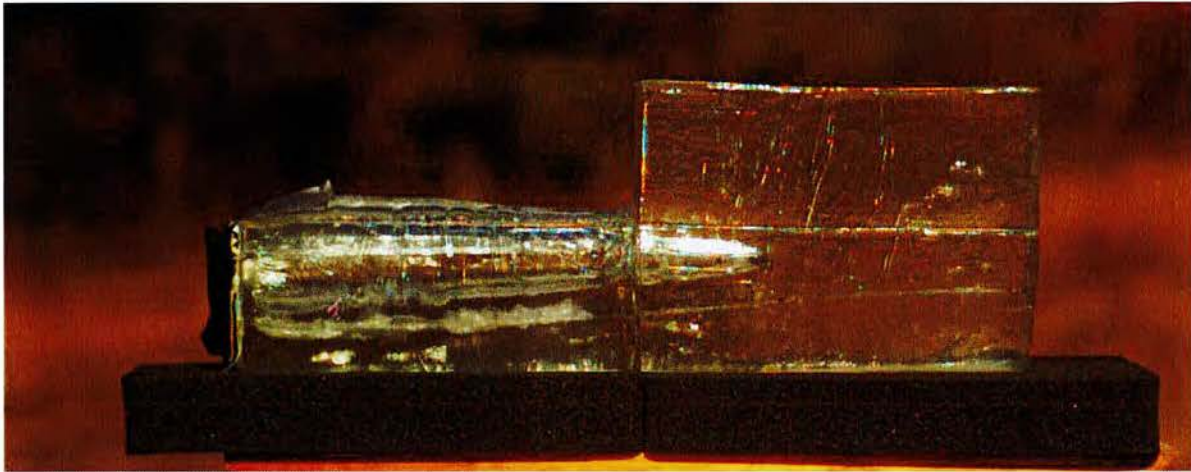


Figure 55. A .626 diameter ball fired from a French 1763/66 musket creating an initial wound cavity in gelatin. The ball entered the block at 1155 f/s, has passed through one 16-inch long block, and is moving through the second block.

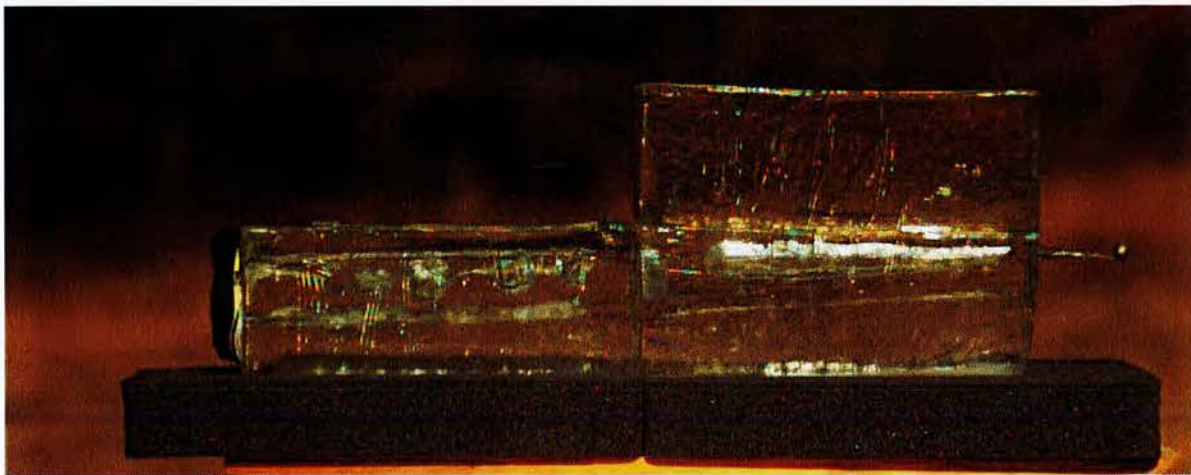


Figure 56. The .626 diameter ball fired from the French 1763/66 musket at it exits the second gelatin block at a velocity of 280 f/s. The ball has passed through 32 inches of gelatin and lost 745 f/s of velocity passing through the tissue simulant.

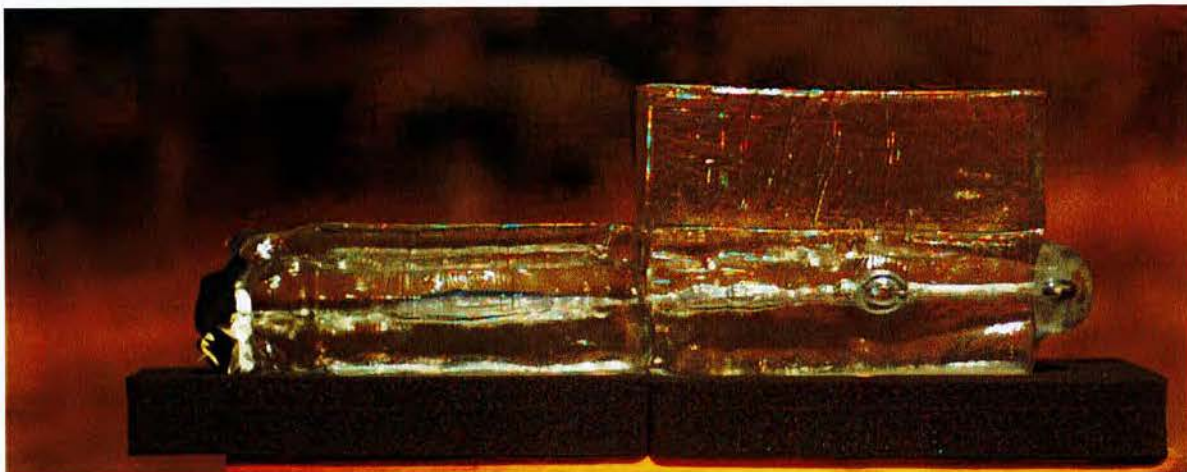


Figure 57. A .626 diameter ball fired from the French 1763/66 musket at 785 f/s passes through 32 inches of gelatin but does not break the plane of the tissue simulant.

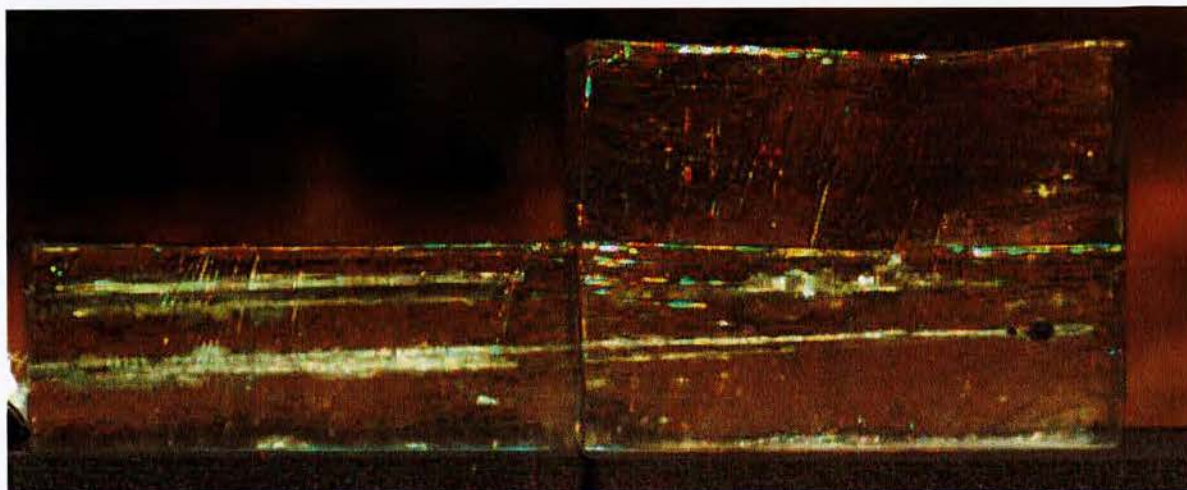


Figure 58. A .626 diameter ball fired from the French 1763/66 musket at 785 f/s that rebounded or was pulled back into the tissue simulant coming to rest about 30 inches from the entry point. Note the dark spot to the left of the ball, which is a piece of fabric carried into the wound channel.



Figure 59. Fragments of fabric recovered from gelatin wound tracks. L to R. recovered from entry site 4 inch in, 12 inches in, 12 to 14 inches in, 14 to 16 inches in, 15 to 16 inches in and 30 inches in. In a real wound track the fabric would be sources for infection and sepsis, a known issue in eighteenth century medicine.

The Thomas Earle fowler was fired four times at the gelatin blocks. The first two shots used the .58 diameter ball without patch and with an 85-grain charge. The first shot achieved a muzzle velocity of 1285 f/s, passed through 32 inches of gelatin and exited the blocks at 550 f/s. The second shot entered the blocks at 1340 f/s and passed through 32 inches of gelatin. The third shot had the powder charge reduced to 75-grains. It entered the block at 1140 f/s and exited the block. The fourth shot, also using the 75-grain powder charge, entered the block at 1155 f/s and exited the block after passing through 32 inches of gelatin at 280 f/s. The ball was recovered on the ground surface at 100 yards from the shooting bench and 75 yards beyond the gelatin block position.

Ball Penetration and Deformation

The dynamics of bullet penetration in any media are complex and dependent on velocity at the time of impact, the density of the media it strikes, and drag or resistance on the bullet during flight. Miller and Bailey's (1979:449-463) study of drag drawn from eighteenth and nineteenth

cannon firing sources demonstrated that with the development of the 1868 Bashforth chronographic instrument, reasonably accurate velocity and drag measurements were attainable. They also found the earlier ballistic pendulums (ca. 1787 and ca. 1839) were less accurate than the Bashforth chronograph, but still produced reasonable data. Using modern data and mathematical formulae they created drag models for spheres ranging in velocity from Mach 0.3 to Mach 2.0. Their basic research is incorporated into the ballistic models employed in this study.

Likewise, bullet deformation is dependent on the same issues. MacPherson (1994) studied and modeled bullet penetration as related to incapacitation from wound trauma. Bullet penetration in any substance, be it soil, wet or dry wood, or human tissue, is dependent on several factors including the energy it has when it strikes a substance. This is kinetic energy, and here we express it as foot/pounds (ft-lbs). A soft lead bullet traveling at a velocity has mass (weight), speed, and stored but dissipating energy as it fights resistance or drag. The object or media the bullet strikes, if soft, transfers the kinetic energy of the bullet in the form of heat; if hard the bullet is deformed to some degree or another as a function of the laws of thermodynamics. The force that results in bullet deformation is simply Newton's Third Law of Motion, for every action there is an equal and opposite reaction. There is not an absolute direct correlation to bullet deformation since kinetic energy and damage is not due directly to energy absorption, but to the amount of force per area on the bullet and media. Bullets behave according to physical laws, and by knowing the velocity, mass (weight), and other variables bullet deformation and penetration can be mathematically modelled (MacPherson 1994:11-14). Modern ballistic calculators take these variables into account when calculating muzzle velocity, changes in velocity over time, air resistance (drag), and gravity, to determine bullet speed loss over distance and drop from the angle of the firearm muzzle relative to the ground surface.

In penetration studies the terms low and high velocity have specific definitions. Low velocity is considered to be a bullet traveling at 300 f/s or less, while high velocity is considered to be a bullet traveling at 600 f/s or more (MacPherson 1994:74-77). For all practical purposes all charges fired in the arms in this experiment achieved high velocity as used in penetration and wound trauma studies.

Bullet penetration and expansion or deformation is modelled using the principles of fluid dynamics. Bullets expand more in higher density fluids and less in lower density fluids. Lower density fluids include water, tissue, tissue simulants, and experiments have shown that bullets penetrate and expand or deform in consistent ways in these lower density situations (MacPherson 1994:122-125; Fackler 1988:555-557).

Bullets yield or deform in response to the force applied on it. A ball striking a hard strong solid (e.g. rock, hard woods, etc.) will deform at relatively low velocities because the hard and rigid surfaces produce large forces on the bullet (Kerkhoff et al. 2015; Mattijssen et al. 2016). The diameter of the bullet and its mass (weight, usually expressed as sectional density) is another factor in the amount of deformation that occurs when a ball strikes a hard or rigid surface. Pure or dead soft lead (not pure in the chemical sense, but with impurities present as such low levels as to not be significant) is very ductile and deforms significantly based on static loading as confirmed in experiments (MacPherson 1994:127) using spherical balls and black powder loads.

The experiments show that lead spherical balls show slight deformation at about 690 f/s velocity and increase accordingly at higher velocities when fired into soft fluids like tissue or water.

Lucien Haag (personal communication December 15, 2004) conducted an experiment firing lead spherical balls from modern cartridge pistols and rifles using controlled black powder charges. He fired each shot into a water tank at velocities ranging from 360 f/s to 1026 f/s for .45-caliber balls in a pistol and ranging from 1049 f/s to 1529 f/s for .45-caliber balls fired from a rifle. His investigation found the higher the velocity the greater the deformation. His lower velocity impacts ranging from 630 f/s to 1026 f/s had virtually no deformation while rounds fired above 1049 f/s to 1138 f/s showed some slight flattening. Recovered balls fired between 1281 and 1336 f/s were showed flattening to nearly half the diameter, while the round fired at 1529 f/s was nearly completely flattened. Haag's experiments largely confirm the work MacPherson (1994).

Bullet Deformation Correlated with Velocity

Deformation seen in the lead balls fired in the various guns in the current experiment largely mimic the results reported by MacPherson (1994:126-130). Balls fired into tissue simulant, the loose sand backstop, dry soft woods, and wet pine, showed the least deformation. The smaller balls, .520-caliber and .580-caliber showed the least deformation and the larger balls, .69-caliber, showed the largest deformation at any given velocity, which is consistent with metal yielding functions correlated to the bullet's sectional density (MacPherson 1994:142-143). These phenomena are clearly illustrated in the following images and graphic representations.



Figure 60. Unfired buckshot and bullet examples as used in the live fire experiments. l to r – 0.28-inch buckshot, 0.31-inch buckshot, 0.520-inch ball, 0.580-inch ball, 0.626-inch ball, 0.662-inch ball, and 0.69-inch ball.



Figure 61. Unfired .069-inch ball, .069 ball fired at 600 f/s that struck ground surface at 100 yards, .069 ball fired at 630 f/s that struck a wood table, foam, and ballistic gel at 25 yards and was collected laying on the foam at the back of 32 inches of ballistic gel, and a .069 ball fired at 630 f/s that was captured in the ballistic gel at 25 yards after passing through 28 inches of gel. Note fabric impression on second and fourth balls.



Figure 62. Unfired .0626- inch ball, .0626 ball fired at 775 f/s recovered from a soil and sand backstop at 100 yards and a .0626 ball fired at 785 f/s and captured in ballistic gel at 25 yards after passing through 30 inches of gel. Note ramrod mark on second ball and fabric impressions on third ball.



Figure 63. Top row: Unfired 0.282-inch buckshot and fired 0.282-inch buckshot at 865 f/s. Second row: Unfired 0.626-inch ball and fired 0.626-inch ball at 865 f/s. Third row: Unfired 0.69-inch ball and fired 0.69-inch ball at 870 f/s. Note each recovered in the sand and soil backstop at 100 yards.



Figure 64. Unfired 0.626-inch ball, fired balls l to r fired at 905 f/s, 960 f/s, 960 f/s, and 1090 f/s. All balls recovered at 100 yards in sand and soil backstop. Note third ball from the left passed through a pine 4x4 target frame upright and the fourth ball from left also struck the edge of the pine target frame before embedding in the backstop.



Figure 65. Left column, unfired 0.626-inch ball, fired 0.626 balls at 1110 f/s and 1175 f/s, both found in sand and soil backstop. Second column, unfired 0.282 buckshot and fired 0.282 buckshot at 1110 f/s found in sand and soil backstop. Third column, unfired .580-inch ball and fired 0.580 ball at 1135 f/s found in sand and soil backstop. Fourth column, 0.580 ball fired at 1155 f/s, and Fifth column, 0.580 ball fired at 1170 f/s and found in soil and sand backstop. All balls recovered at 100 yards.



Figure 66. Top row, Unfired 0.626-inch ball, fired 0.626 ball at 1205 f/s and found in sand and soil backstop, fired 0.626 ball at 1215 f/s which nicked the target frame post and was found in the sand and soil backstop. Bottom row, Unfired 0.520-inch ball, fired 0.520 ball at 1215 f/s that hit oak palisade paling and ricocheted back into sand and soil backstop, fired 0.520 ball at 1250 f/s which hit a pine palisade paling and ricocheted back into sand and soil backstop, 0.520 ball at 1240 f/s that struck an oak palisade paling and fell to the ground below the fence, and 0.520 ball fired at 1285 f/s that went through a 4x4 pine target frame upright and was recovered in the sand and soil backstop. All balls found at 100 yards.



Figure 67. Unfired 0.520-inch ball and two fired 0.520 balls, center fired at 1345 f/s and hit pine target frame and right fired at 1350 f/s and hit pine target frame. Both found in sand and soil backstop at 100 yards. Note banding on last ball from being upset in firing from the musket.



Figure 68. Unfired 0.580-inch ball and fired balls, second – fired at 1415 f/s and struck oak palisade paling and found in sand and soil backstop below fence, third – fired at 1435 f/s and found in sand and soil backstop, fourth – fired at 1480 f/s and found in sand and soil backstop. All balls recovered at 100 yards.

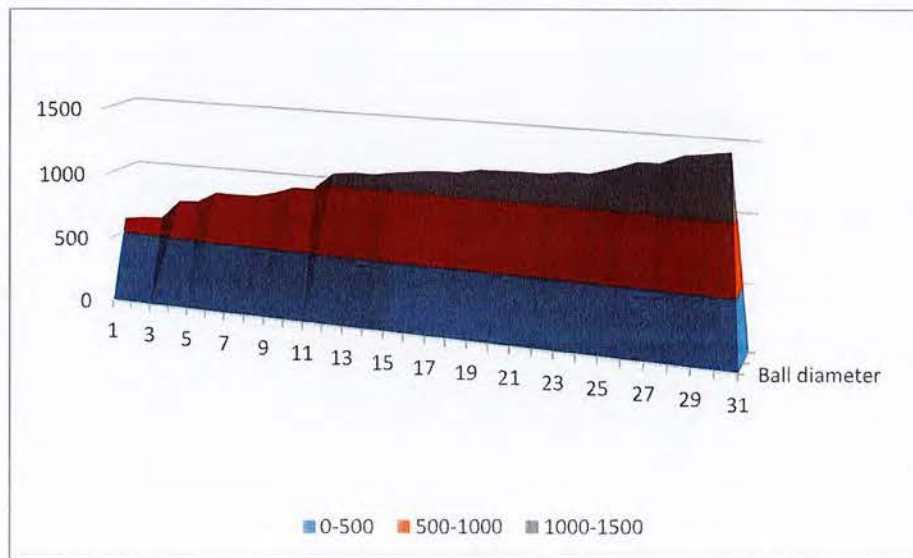


Figure 69. Flattening is observed on balls as velocity increases regardless of ball diameter. The greater the muzzle velocity the larger the degree of flattening observed.

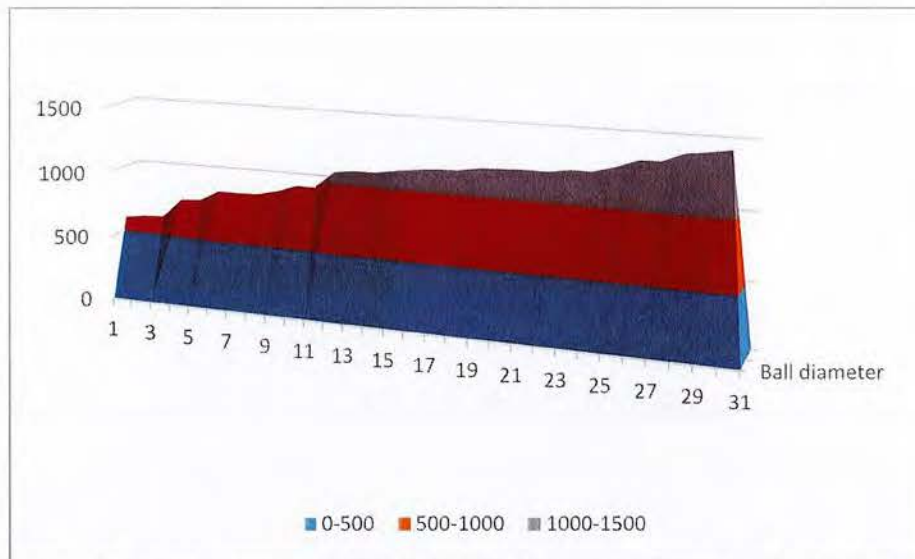


Figure 70. Change in diameter, A, observed on balls as velocity increases regardless of ball diameter. The greater the muzzle velocity the larger the degree of diameter A change observed.

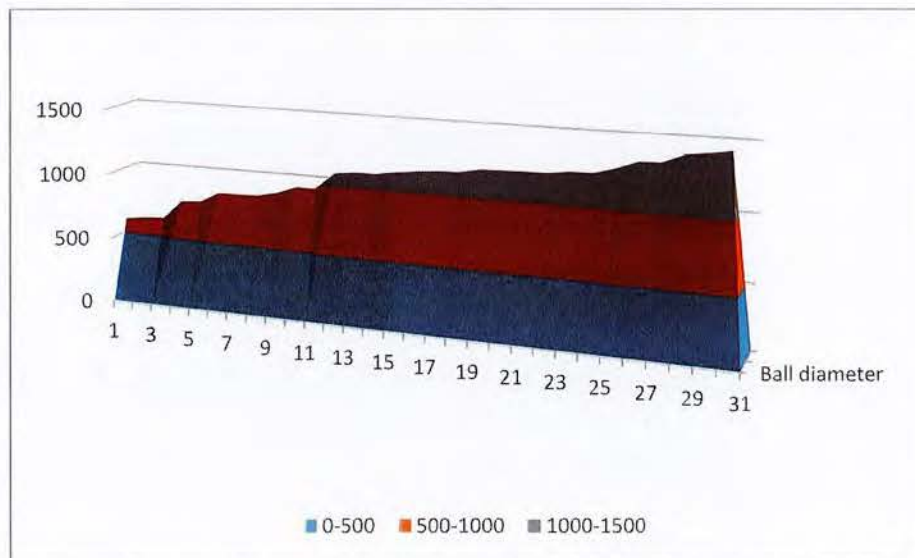


Figure 71. Change in diameter, C, observed on balls as velocity increases regardless of ball diameter. The greater the muzzle velocity the larger the degree of diameter C change observed.

The graphs of relationship of ball deformation to velocity clearly show a general linear trend, in that that the greater the velocity the greater the deformation. A scatter plot with a linear regression trend line confirms this relationship. However, the relationship can only be considered as a general trend, as the variable of the media which a bullet strikes is not likely to be found in the archaeological record.

Lead Bullet Deformation Index

For more than 30 years an intuitive scale based on personal experience with shooting muzzle loading weapons has been used to assign value to impact deformed bullets. The scale is descriptive using Low, Medium, and High Velocity Impact terms as a means of defining impact deformation (e.g. Scott et al. 1989). The current live fire experiments where bullets fired at known velocities were recovered allows a new more quantitative-base index scale to be suggested. While this scale has recognized weaknesses, it does refine and replace the even less precise Low, Medium, and High Velocity Impact scale that is in common use (e.g. Scott et al. 1989).

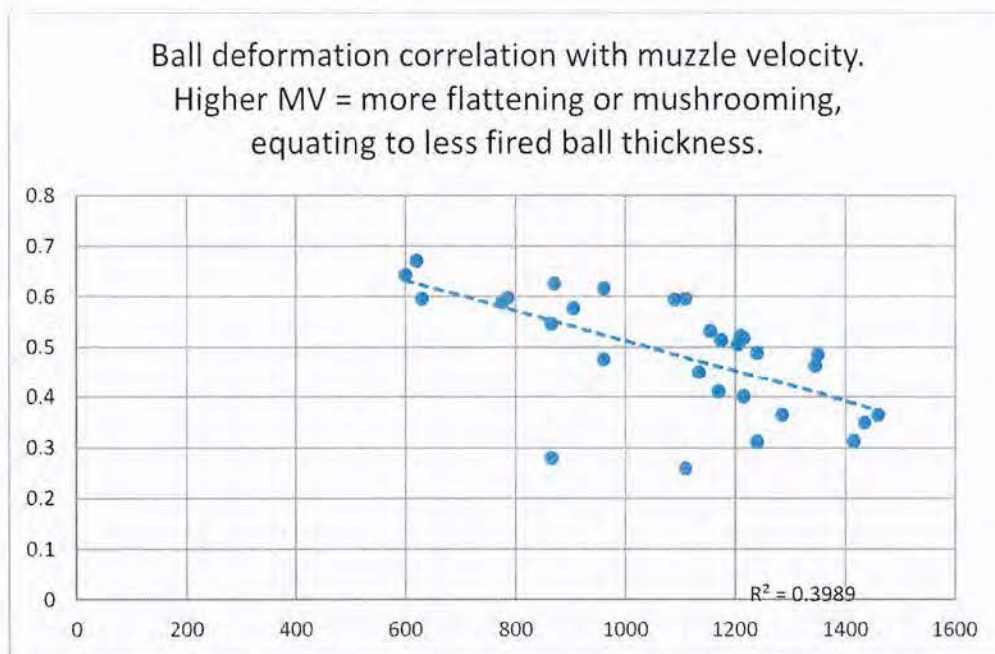


Figure 72. Muzzle velocity compared to thickness or flattening of fired balls. The fired ball thickness is in tenths of inches on the left and muzzle velocity is shown on the bottom as feet per second. There is general agreement that balls flatten at higher velocities, but the linear regression trendline indicates the relationship is only about 40%. This further reinforces the fact that the nature of the media the ball strikes at the end of its flight as well as remaining velocity and kinetic energy are significant factors in deformation.

Using the ball deformation data acquired during the live fire experiment we present an ordinal or nominal bullet deformation rating scale to equate to an approximate velocity range. We emphasize that the **Lead Bullet Deformation Index** scale we propose cannot be used as a one-to-one correlate to absolute velocity and the amount of deformation, rather it is intended to give the user an approximation of the relationship between velocity and deformation. Using the ordinal rating scale model results in a number that can be tested using ANOVA, Regression, or Chi-square tests.

We define the **Lead Bullet Deformation Index** to be:

Based on a mixed qualitative and quantitative set of observations of the fired bullet a rating scale number can be determined. Measurements should include the maximum diameter (diameter A), the thickness or amount of flattening (diameter B), and the minimum diameter that is not in the plane of deformation (diameter C). These data can be plotted and trendlines applied through scatter plots and various statistical regression procedures to observe and refine trends.

Qualitative observations range from the amount of impact scarring present from minimal to extreme as to the degree of impact flattening (commonly called mushrooming) the bullet exhibits.

The ordinal scale is:

1. Likely velocity is less than 800 f/s based on little or no visible scarring or flattening. Diameter measurements are essentially consistent for the three measured points on the ball.
2. Likely velocity is between 800 and 1100 f/s based on slight to moderate visible impact scarring, possibly some imbedded residue or negative impressions (sand or rock inclusions or impressions), and some impact flattening that is less than half the diameter of the ball. Diameter measurements show flattening to less than one half the ball's original diameter or caliber.
3. Likely velocity is greater than 1100 f/s based on significant impact scarring and flattening of ball to becoming totally mushroomed. Measurements should reflect the thickness of the flattening relative to the measured diameter as extreme.

We suggest when there is a question of whether a ball falls in one ordinal range or another that it is appropriate to use an 0.5 number. An example is that a ball shows some minimal impact scarring and some moderate flattening would be assigned a 1. However, the measurements in the A and C axes are essentially the same, but the thickness or flattening measurement is notable and could be assigned a 2. We suggest assigning it a 1.5 rating. That data can be used to refine any statistical analysis. We do not endorse any finer intermediate resolution between the numbers as this will only be pure speculation and confuse any statistical analysis.



Figure 73. Fired ball that struck wood showing little to no impact deformation. This would score as a 1 on the Bullet Deformation Index indicating a likely velocity of less than 800 f/s.



Figure 74. Fired ball with moderate impact scarring and deformation that is consistent with a Bullet Deformation Index of 2 indicating a likely velocity of 800-1100 f/s.



Figure 75. Fired ball that hit a palisade post with a wire tie. The impact scarring is moderate, but the impact deformation is more than moderate but not extreme. It scores a 2.5 on the Bullet Deformation Index.



Figure 76. Two fired balls with significant impact scarring as well as impact deformation. The left ball shows significant flattening and the right ball also shows significant deformation. The left ball is scored at 3 and the right ball could be scored a 2.5 on the Bullet Deformation Index.



Figure 77. A Fowler .580-caliber ball hit on a live oak palisade paling with insets showing the complete flattening or mushrooming effect of a high velocity hit on a hard media. The muzzle velocity was 1240 f/s. The ball scores a 3 on the Bullet Deformation Index.

Other Observations

Sometimes balls fired from muzzle loading firearms exhibit a variety of characteristics that can be mistaken for impact deformation. These can be identified and interpreted with careful observation and analysis. Sivilich (2016), Foard (2012), Foard and Morris (2012) and Harding (2012) have observed, described, and interpreted these and other non-impact characteristics on spherical lead bullets from a variety of archaeological contexts. Sivilich was one of the first to use live fire data to validate interpretations of impact and non-impact marks on fired balls. The current live fire empirical evidence further verifies and validates the archaeological based descriptions and interpretations as well as those of Sivilich (2016)

The live fire recovered bullet data confirm characteristics found on balls relate to the loading or the type of load. These characteristics, like ramrod marks from loading the round, or faceting or multiple dimples on one surface likely indicate a buck and ball round. Another characteristic is a smooth band completely or partially around the ball. The banding effect occurs when a ball is upset in the bore during loading, slightly compressing the bullet. When fired the propellant gases further force the ball against the bore creating the band. It is a tell-tale indication of a ball being fired from a smooth bore gun. The following figures illustrate several of these observed non-impact related characteristics.



Figure 78. Typical denting and slight flattening caused by a ramrod head being forced against the ball during the loading of a muzzle loading firearm. There are different ramrod shapes for different firearms types and that data can be used to aid in identification of the type of gun in which the ball was fired.



Figure 79. A fired ball with three dimples or small facets adjacent to one another. This dimple pattern is typical of firing deformation when three buckshot are placed on a larger ball, known as a buck and ball round. The flattening observed on the left side of the ball is impact deformation.



Figure 80. The slight to moderate faceting seen on the two buckshot are typical of buckshot that were in proximity to one another when loaded and fired. The soft lead is compressed in loading and firing causing the buckshot to press against and deform one another. The flat area on the left side of the right buckshot is a ramrod impression.

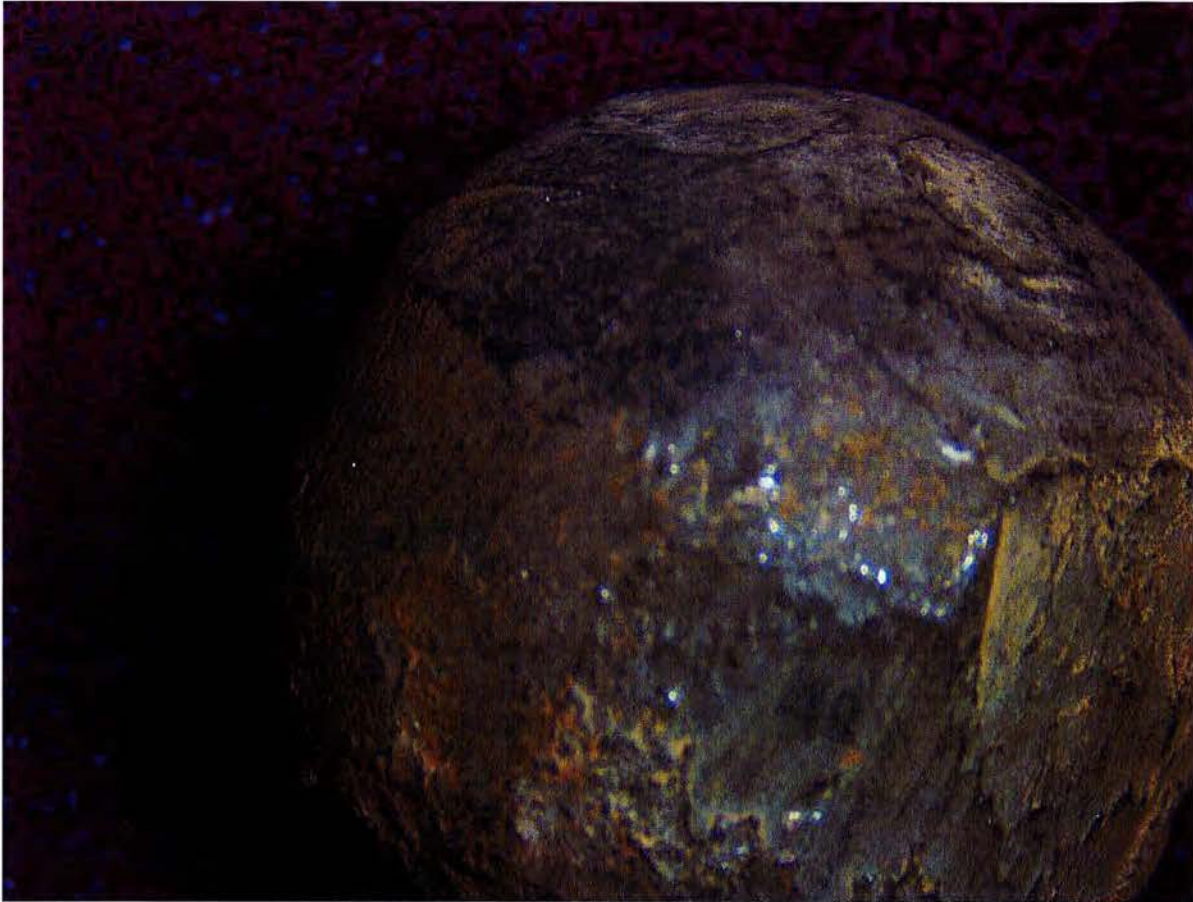


Figure 81. A 40x magnification of the bore band seen on balls fired in smooth bore guns. Note the micro striations run parallel to the line of the bore. This ball also has buckshot dimpling on the upper right surface.

Microscopic examination of fired balls can often reveal a number of other micro characteristics that may aid in identifying the media in which the ball imbedded or passed through. Traces or impressions of wood, soil (e. g. sand or gravel), fabric impressions or fabric adhering to the ball surface, or even bone embedded in the ball aid in the interpretation of the shooting incident under investigation.

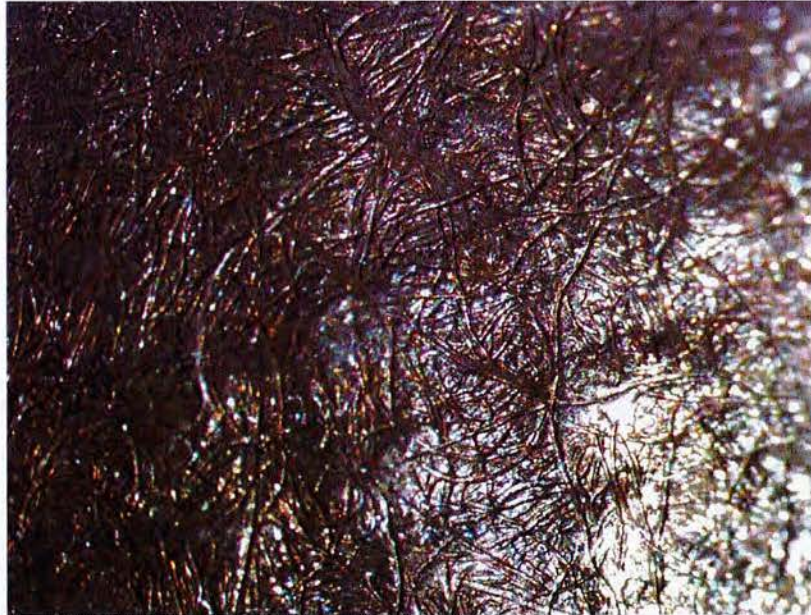


Figure 82. A 75x magnification of the surface of an unfired lead ball. The lines are a result of the differential cooling at a micro scale of the lead ball when it was cast in a mold. Mold lines and these microscopic cooling lines are indicative of a cast ball. These microscopic cooling lines are largely obscured when a ball is fired.



Figure 83. A 60x magnification of a ball fired in the 1728/41 French musket at 870 f/s that hit the sand backstop. Some slight impact scarring is seen in the upper portion of the image and the fine sand particles impressed on the ball as it struck the backstop.



Figure 84. A 40x magnification of a ball fired from the British 1756 Long Land Pattern musket that passed through the simulated uniform cloth and gelatin blocks. The fabric impressed its weave on the ball providing a textile analyst data for interpretation. The raised circular area on the left of the ball is a sprue from casting the bullet in a mold.

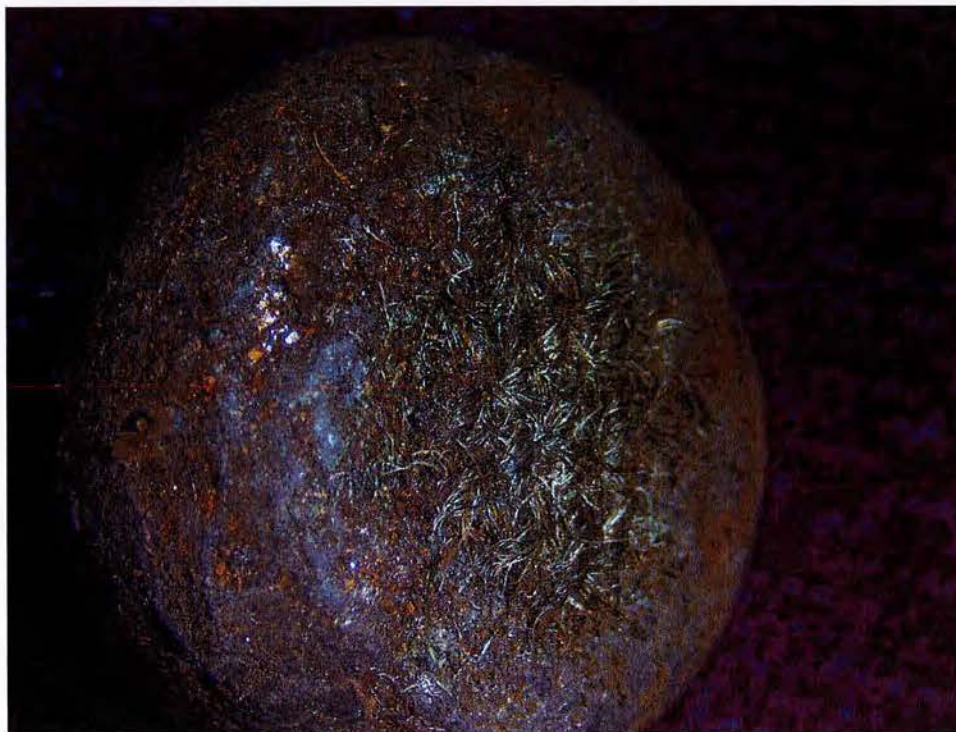


Figure 85. A 20x magnification of a ball fired from the 1763/66 French musket with fabric still adhering to its surface after passing through the simulated uniform cloth and gelatin blocks.

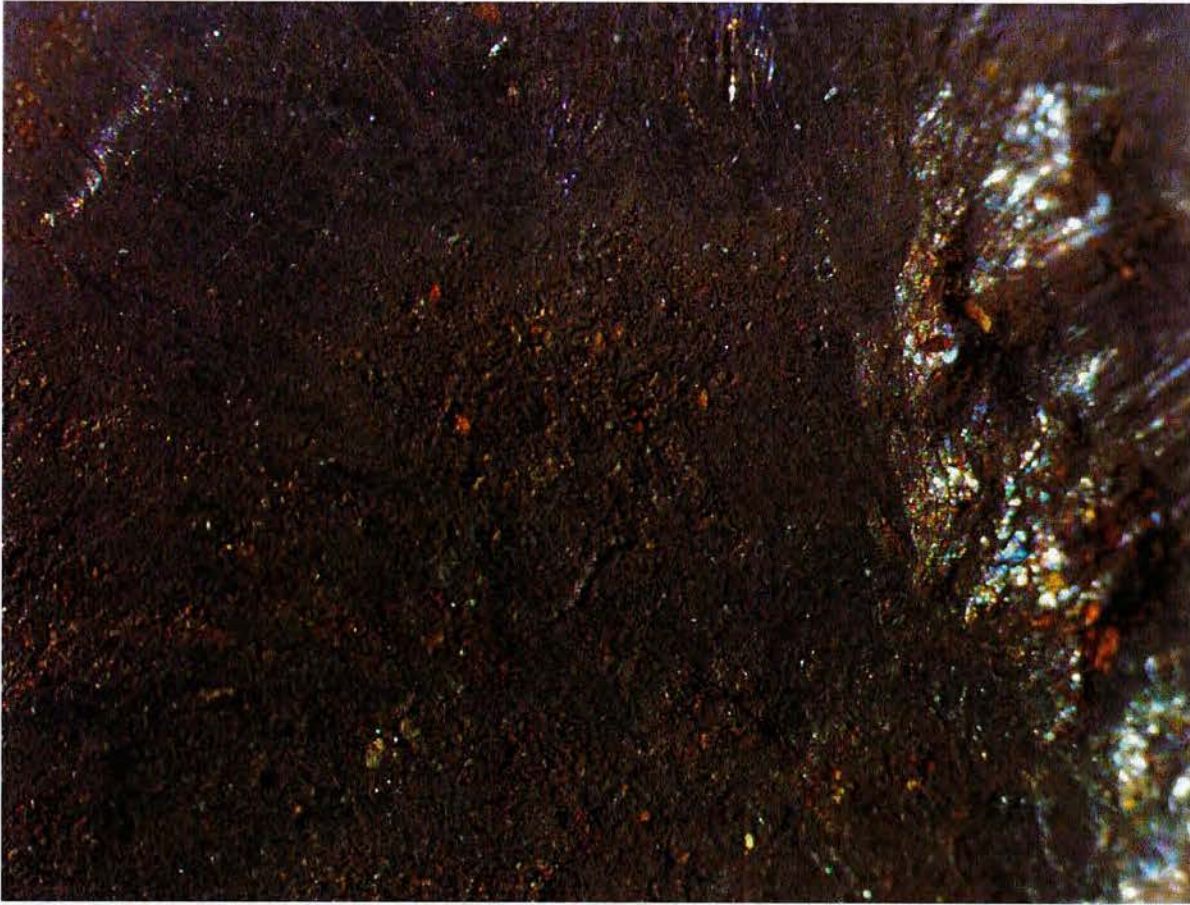


Figure 86. A 75x magnification of a balls surface that shows small fabric threads and impression of soil from passing through the simulated uniform cloth, gelatin blocks, and landing in the soil in front of the target backstop.

Bullets, regardless of form or composition, deform on impact depending on the velocity and the media which it strikes. We observed this on the balls recovered during the live fire experiment, some of which are illustrated here. Balls also embedded in the wood palisade and provided further examples of deformation that couples velocity and media.



Figure 87. A .626 ball embedded $\frac{3}{4}$ inch in a dry loblolly pine post. Note the deformation to the ball is moderate and would fall on the Bullet Deformation Scale as a 2. Pine is a relative soft media which is similar to tissue.



Figure 88. A .580 ball embedded in dry green oak.



Figure 89. The .580 ball removed from the dry green oak. The ball is significantly deformed having hit at a higher velocity into a hard wood media. The bullet deformation is a 3 on the Bullet Deformation Scale.

Ball Deformation and Determination of Original Caliber

The deformed pure or soft lead spherical ball is particularly noted for being difficult to determine its original nominal caliber in archaeological contexts due to impact. Several formulae have been advanced that use the weight of the deformed spherical ball to calculate its approximate original diameter. Arrowood and Berglund (1980) developed one formula that gave a 99.5% level of confidence when at \pm three standard deviations. Daniel Sivilich devised a similar formula (1996; 2009) with only one standard degree of error which has proved quite reliable and replicable. Branstner (2006) attempted to improve the Sivilich formula by recalculating the density of lead and reformulating the Sivilich formula. Branstner devised a table of lead ball diameters based on weights that range from 0.228 inch in diameter to 1.67 inch in diameter. Sivilich (2016:25-27) revised his formula and included new data on lead density to more accurately determine an original caliber, with only one degree of standard error.

We tested the revised Sivilich formula against the recovered fired balls from the live fire experiment. We knew the original ball diameter weight before firing and we weighed the fired balls as well as calculated the fired ball weight loss by caliber and average weight loss for each ball diameter. The weight of the recovered balls was used to test the 2016 Sivilich formula (See Appendix B for a blind study of the known velocity balls and their deformation).

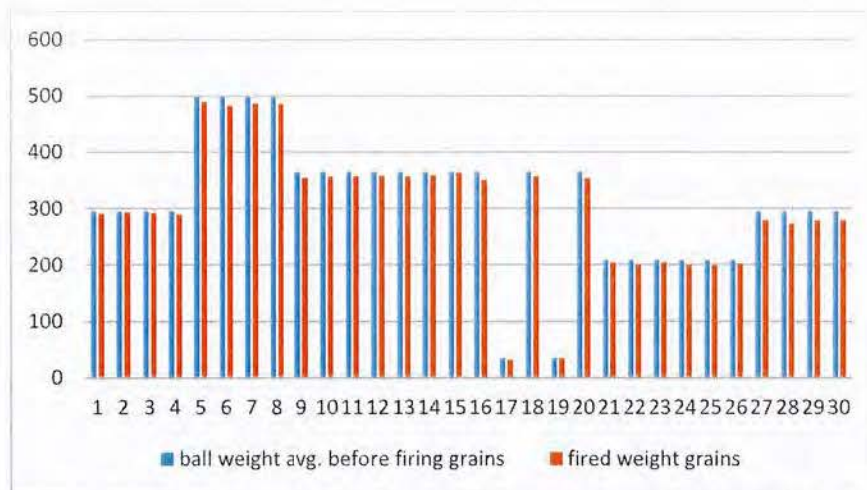


Figure 90. Ball weight before firing compared to weight loss with recovered balls. Note that items 1-4 are .580 balls, 5-8 are .69 balls, 9-16, 18, and 20 are .626 balls, 17 and 19 represent .282 buckshot balls, 21-26 are .520 balls, and 27-30 are .580 balls. The overall average weight loss of fired balls is 2.4%, although this generally increases as velocity increases ranging from 0.4 to 7.5%.



Figure 91. The percent of fired ball weight loss compared to muzzle velocity. The weight loss range is from 0.4 to 7.5%. To some degree the fired ball weight loss is partially dependent on the hardness of the media it struck when the ball's flight terminated.

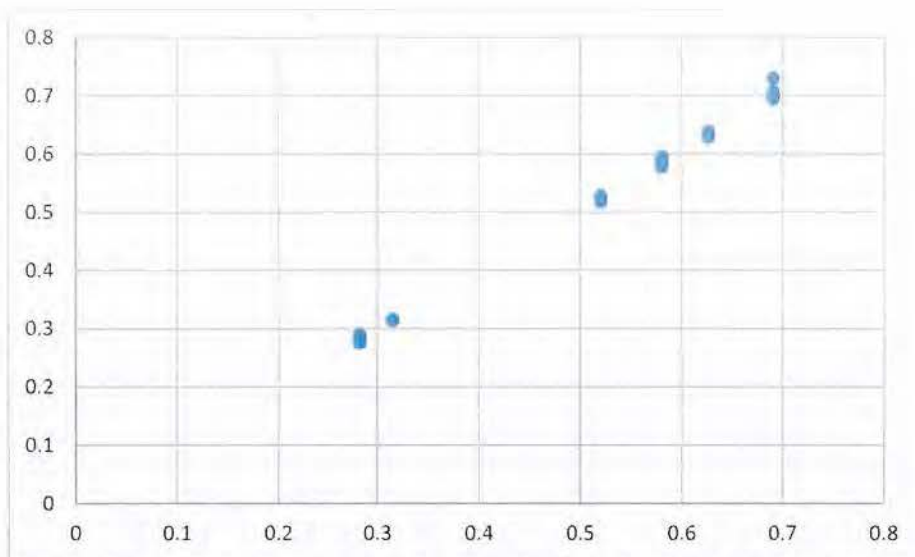


Figure 92. The measured ball diameter compared to the calculated ball diameter using the Sivilich Formula (2016). The differences are well within one standard deviation with an R value of .998.

The revised Sivilich Formula proved exceptionally reliable and accurate. A regression correlation was run comparing the two data sets. Sivilich's Formula tends to overestimate the ball diameter from a few thousandths of an inch to about one-hundredth of an inch. The R value was calculated to be .998 with less than one standard error of deviation. The R value is near ideal and proves the Sivilich Formula to be accurate and reliable for calculating the original ball diameter using weight or mass from recovered archaeological specimens.

Summary and Conclusions

The Colonial firearms live fire experiment can be characterized as an unqualified success. The intent behind the investigation was to determine the external ballistic bullet performance of a series of smoothbore shoulder fired guns of the type commonly used during the American Revolution. The general premise or research design that drove the experimental investigation was to document the fired ball performance in terms of muzzle velocity, penetration capability, and bullet deformation as it terminated its flight. Prior to this controlled experimental work there are only a limited number of controlled shooting studies using Colonial era or replica weapons. This study not only recovered bullets fired at different media; tissue simulant, sand, and wood; it also used high speed videography to determine initial muzzle velocity for each shot. The collected information was analyzed and compared to models of lead sphere external ballistic performance.

Our data exhibits excellent correspondence with ballistic performance models, further validating those models and allowing us to compare our data findings with various data sets. A particularly

valuable finding is that the approximate original caliber of fired and deformed lead balls can be accurately determined using the Sivilich Revised Formula. This validation of the Sivilich Formula is of real value to archaeological investigations.

Our live fire experiments were designed to determine Colonial era musket and fowler bullet performance. Accuracy was not a major component of the study; however, general shot accuracy was noted. The least accurate firearms were the British Long Land pattern muskets. Regardless of range the shots did hit the man-size torso target or were near misses, but had a very wide spread, often exceeding 30 inches. The 1740 Potsdam musket never struck the target at 100 yards. In part this may have been a function of the shooter's experience level, but given the range of shooter experience in the eighteenth century this is not unrealistic. The British Artillery Carbine and the French pattern muskets achieved good target hits at all ranges at about 75% of the shots fired. The Thomas Earle Fowler had an exceptional record for accuracy. Regardless of shooter experience, and nearly every shooter fired the fowler at least once, over 85% of the shots hit the target at all ranges. This led several of the shooters to observe they would rather have been Minute Men or Colonial Militia than British or Hessian troops during the Revolutionary War.

Another valuable lesson derived from the live fire experiments is the validation of bullet deformation and a general correlation with velocity. We present a Lead Bullet Deformation Index that we believe many archaeologist will find useful. The LBDI we present needs additional testing and validation, but we believe that it has utility as an independent ordinal scale to assess impact deformation on conflict sites. The LBDI assessment can be of use in determining possible firing line distances on battlefields which will expand the archaeological interpretative potential of bullet datasets.

The microscopic examination of unfired and fired lead balls revealed changes in the microstructure of the balls' surface that are observable and clear. We have not yet examined the effect of patination on the observability of those surface changes in archaeological samples, but knowing they do and did exist on fresh lead bullets offers another line of investigation and interpretation to determine if a ball has been fired or not.

Much of the work we undertook was designed to aid archaeologists in better understanding of the potential information yields that can be gained from bullet analysis from archaeological sites. We have focused on conflict sites specifically and the role bullet analysis has in yielding information that expands and enhances their interpretive value. An additional intent in conducting the live fire experiments is to provide well controlled and defined data to forensic firearm examiners so they may use the information to identify historic firearm types involved in law enforcement cases either by inclusion or exclusion. We believe the data presented here will aid firearms examiners with case work when it involves shooting incidents with smoothbore muzzle loading black powder firearms.

The goals and objectives of this project were to collect data and conduct live fire experiments with appropriate replica Colonial firearms. The goals also included recording that information and disseminating it to battlefield archaeologists, interpreters, reenactment groups, and others to

enhance various aspects of public interpretation regarding of the effectiveness of selected firearms in combat in the past. Firearms had an enormous impact on the European settlement and conquest of the western hemisphere. We see this report as the first step in creating a wide-ranging data base on effectiveness and external ballistic performance of firearms in general, and in this specific study of Colonial era muskets and fowlers specifically. We also see this report as the first step in creating a data base on bullet performance of firearms that were used in the New World after 1492.

This study demonstrates the need to conduct additional live fire experiments of with a variety weapons and firearms of the types used in the prior to the American Revolution, during the War of 1812, Mexican War, Civil War, and Indian Wars. Live fire experiments with bows and arrows, lances, crossbows, matchlocks and common black powder weapons should be undertaken. Using this or similar data collection models to acquire muzzle and downrange velocities will result in better comparative observations of bullet velocity for a given weapon type as well as ascertaining when the projectile falls below a velocity and kinetic energy threshold that could cause death or a serious wound. Continued controlled live firing of weapons into ballistic gelatin will further assess wounding and lethality effects of various ammunition types in simulated tissue. Firearms functioned as tools throughout their history, evolving in concert with the cultures and technologies in which they were used. Firearms deserve serious study as points of industrial development and evolution and as factors in affecting cultural change across the globe.

References Cited

Arrowood, Michael C. and James S. Bergland

1980 Classification of Lead Ball: A Mathematical Approach. *Association of Firearm and Tool Mark Examiners Journal* 12:40-46.

Adye, Ralph Willett

1800 *The Little Bombardier and Pocket Gunner* T. Egerton Military Library, London.

Babits, Lawrence E.

2002 "The Whites of Their Eyes:" Buck and Ball and Bayonet Charges, Bunker Hill to Gettysburg. Program in Maritime Studies, East Carolina University, Greenville, NC.

Boackle, Mark

2011 The Use of Perma-Gel Testing Medium for Comparison of Terminal Performance of Different Caliber Pistol Calibers. *The Journal of the Association of Firearm and Tool Mark Examiners* 43(2):146-153.

Branstner, Mark C.

2008 The Problem with Distorted, Flattened, Spent, and Otherwise Mangled Lead Balls: A Simple Remedy. *Illinois Archaeology* 20:168-184.

Brown, William L., III

1999 *Thoughts on Men's Shirts in America: 1750-1900*. Thomas Publications, Gettysburg, Penn.

Buchanan, Brenda J. (ed.)

1996 *Gunpowder: The History of an International Technology*. Bath University Press, UK.

Cayton, John C.

1984 Blackpowder Firearms, Powder Residue, and Ball Penetration. *Association of Firearm and Tool Mark Examiners Journal* 16(4):80-81.

de Marolles, Magné and W. Cleator

1789 *An Essay on Shooting* T. Cadell in the Strand, London.

Dodd, Maclom J.

2006 *Terminal Ballistics: A Text and Atlas of Gunshot Wounds*. Taylor and Francis, New York.

Fadala, Sam

1988 Penetration of Round Ball. *Association of Firearm and Tool Mark Examiners Journal* 20(2):135-139.

Fackler, Martin

1988 Handgun Bullet Performance. *International Defense Review* 21(5):555-557.

Foard, Glenn

2012 Battlefield Archaeology of the English Civil War. British Archaeological Reports, British Series 570.

Foard, Glenn and Richard Morris

2012 The Archaeology of English Battlefields. Council for British Archaeology, Research Report 168.

Force, Peter

1846 American Archives: Fourth Series, Volume 6, Documentary History, Primary Sources, Colonies, Colonial, Declaration of Independence, American History, History, Colony, Revolution, Founding Fathers, Constitution, Rebellion, Thomas Jefferson, George Washington, James Madison, George Mason, Patrick Henry, Alexander Hamilton. Washington, D.C.

Garrison, D. H., Jr.

1993 Shooting Reconstruction vs Shooting Reenactment. *Association of Firearm and Tool Mark Examiners Journal* 25(2):125-127.

Grancsay, Stephen V.

1954 Firearms vs. Armor. In *Gun Digest*, edited by John Ambler, pp 9-11, 15. Gun Digest, Chicago, Ill.

Haag, Lucien C.

2001 Black Powder Substitutes: Their Physical and Chemical Properties and Performance. *Association of Firearms and Tool Mark Examiners Journal* 33(4):313-325.

2006 *Shooting Incident Reconstruction*. Academic Press, New York.

2012 Contemporary and Historical Black Powder: Physical and Chemical Properties of Forensic Interest. *Association of Firearm and Tool Mark Examiners Journal* 44(2):92-105.

Hall, Bert

1996 Gunpowder and Early Gunpowder Weapons. In *Gunpowder: The History of an International Technology* edited by Brenda J. Buchanan, pp 121-136. Bath University Press, UK.

Harding, D. F.

2012 *Lead Shot of the English Civil War: A Radical Study*. Foresight Books, London

Herring William G.

1971 Ballistics for Muzzle Loaders, Part 1. *Muzzle Blasts* 33(4):12-13.

1972a Ballistics for Muzzle Loaders, Part 2. *Muzzle Blasts* 33(5):6-7.

1972b Ballistics for Muzzle Loaders, Part 3. *Muzzle Blasts* 33(7):6-7.

1972c Ballistics for Muzzle Loaders, Part 4. *Muzzle Blasts* 33(9):5-7, 28.

Howard, Robert A.

1996 The Evolution of the Process of Powder Making from an American Perspective. In *Gunpowder: The History of an International Technology* edited by Brenda J. Buchanan, pp 3-24. Bath University Press, UK.

Hueske, Edward E.

2006 *Practical Analysis and Reconstruction of Shooting Incidents*. Taylor and Francis, New York.

Hughes, B. P.

1969 *British Smooth-bore Artillery: The Muzzle Loading Artillery of the 18th and 19th Centuries*. Arms and Armour Press, London, England.

1974 *Firepower: Weapons Effectiveness on the Battlefield, 1030-1850*. Charles Scribner Sons, New York.

1983 *Artillery Tactics from Marlborough to Wellington*. Clinton Bird, Chichester, Sussex, England.

Kerkhoff, Wim, Ivo Alberink, and Erwin J. A. T. Mattijssen

2015 An Empirical Study on the Relation Between the Critical Angle for Bullet Ricochet and the Properties of Wood. *Journal of Forensic Sciences* 60(3):605-610.

Kidwell, Claudia B. and Margaret C. Christman

1974 *Suiting Everyone: The Democratization of Clothing in America*. National Museum of History and Technology, Smithsonian Institution Press, Washington. D.C.

Klatt, Paul E.

1999 Musket Cartridges of the American Revolution. *Gun Report* 45(7):20-24.

Krenn, Peter, Paul Kalaus, and Bert Hall

1995 Material Culture and Military History: Test-Firing Early Modern Small Arms. *Material History Review* 42:101-109.

La Garde, Louis A.

1991 *Gunshot Injuries: How They Are Inflicted, Their Complications, and Treatment*. Lancer Militaria, Mt. Ida, Ark. (reprinted from 1916 edition).

MacPherson, Duncan

1994 *Bullet Penetration: Modeling the Dynamics and the Incapacitation Resulting from Wound Trauma*. Ballistic Publications, El Segundo, CA.

Mattijssen, Erwin J. A. T., Ivo Alberink, Suzanne D. Brouwer, and Wim Kerkhoff

2016 The Influence of Wood Grain on the Bullet's Ricochet Behavior. *Journal of Forensic Sciences* 61(3):765-772.

Mattoo, B N.

1969 Shot Penetration from Ballistic Data. *Journal of Forensic Sciences* 14(4):521-527.

Miller, Donald and Allan Bailey

1979 Sphere Drag at Mach Numbers from 0.2 to 2.0 at Reynolds Numbers Approaching 10^7 . *Journal of Fluid Mechanics* 93:449-464.

Moore, Robert J., Jr. and Michael Haynes

2003 *Lewis and Clark: Tailor Made, Trail Worn: Army Life, Clothing, and Weapons of the Corps of Discovery*. Farcountry Press, Helena, Mont.

Osborne, Jack

1977a Round Ball Ballistics. *Muzzle Blasts* 38(5):4-5

1977b Round Ball Ballistics (Calculating Trajectory). *Muzzle Blasts* 38(6):17

Potter, Gail Debus and James A. Hanson

2014 *Clothing and Textiles of the Fur Trade, Volume 4 of The Encyclopedia of the Trade Goods of the Fur Trade*. Museum of the Fur Trade, Chadron, Neb.

Richardson, Thom

1999 Ballistic Testing of Historical Weapons. *Royal Armouries Yearbook, Volume 3, 1998*:50-52.

Roberts, N. A., J. W. Brown, B. Hammett, and P. D. F. Kingston

2008 A Detailed Study of the Effectiveness and Capabilities of 18th Century Musketry on the Battlefield. *Journal of Conflict Archaeology* 4:1-21.

Scott, Douglas D., Richard A. Fox, Jr., Melissa A. Connor, and Dick Harmon

1989 *Archaeological Perspectives on the Battle of the Little Bighorn*. University of Oklahoma Press, Norman.

Seumour, Joseph

2013 A Chart Showing the Results of a 1779 Woolwich Ballistic Test. *Military Collector and Historian* 65(4):373-374.

Sivilich, Daniel M.

1996 Analyzing Musket Balls to Interpret a Revolutionary War Site. *Historical Archaeology* 30(2):101-109.

2009 What the Musket Ball Can Tell: Monmouth Battlefield State Park, New Jersey. In *Field of Conflict: Battlefield Archaeology from the Roman Empire to the Korean War*, edited by Douglas Scott, Lawrence Babits, and Charles Haecker, pp 84-101, Potomac Press, Washington, DC.

2016 *Musket Ball and Small Shot Identification: A Guide*. University of Oklahoma Press, Norman.

Spearman, J. Morton

1828 *The British Gunner*. Allen Parbury, London.

Tascón, Ignacio González, Juan Carlos Jiménez Barrientos, Dolores Romero Muñoz, and Amaya Sáenz Sanz

1996 Black Powder in Mining – Its Introduction, Early Use, and Diffusion Over Europe. In *Gunpowder: The History of an International Technology* edited by Brenda J. Buchanan, pp 205-218. Bath University Press, UK.

Thomas, Dean S.

1997 *Round Ball to Rimfire: A History of Civil War Small Arms Ammunition, Part One*. Thomas Publications, Gettysburg, Penn.

Warlow, Tom

2005 *Firearms, the Law, and Forensic Ballistics*. CRC Press, New York.

Wilkes, Margaret Watters

2016 Parker's Revenge Archeological Project, Minute Man National Historical Park, Lexington, Massachusetts: Final Report for the Friends of the Minute Man National Park. Visual Environmental Solutions, no place given.

Willegal, Mike

1999 The Accuracy of Black Powder Muskets.

(http://www.willegal.net/iron_brigade/musket.pdf, accessed January 10, 2017.

Appendix A

Experiments with 3-D Microscopy in Modeling Bullet Surfaces

A Leica DVM 5000 3-D microscope was used to capture images of some bullet surfaces as an experiment in the applicability of 3-D imaging to bullet analysis. The DVM 5000 microscope complements traditional microscopic inspection and analysis. The microscopic image is displayed directly on a high-resolution monitor and can reach extremely difficult-to-access surfaces. This allows for nondestructive inspection of elements which are difficult to examine using traditional microscope techniques. As an advanced digital microscope, it also offers a variety of quantitative analysis options. Among those are shade relief models of surfaces, colored wire frame models, and calibration functions.

The DVM 5000 has a large array of magnification capabilities. In the case of the lead balls the surface area that could be modeled is limited to a 6 x 6-millimeter area for any given ball tangent. In this experiment balls with fabric impressions were imaged at low magnification to achieve the 6 x 6-millimeter area, then modeled as surfaces to show fabric impressions and impact scarring. Relief models, profiles, and graphic profiles, and wire frame models were collected. The 3-D experiment demonstrates analytical potential, but time constraints prevented detailed comparisons and full analytical capability. More studies are needed to fully explore 3-D modeling potential.



Figure 93. The Leica DVM 5000 3-D microscope setup.

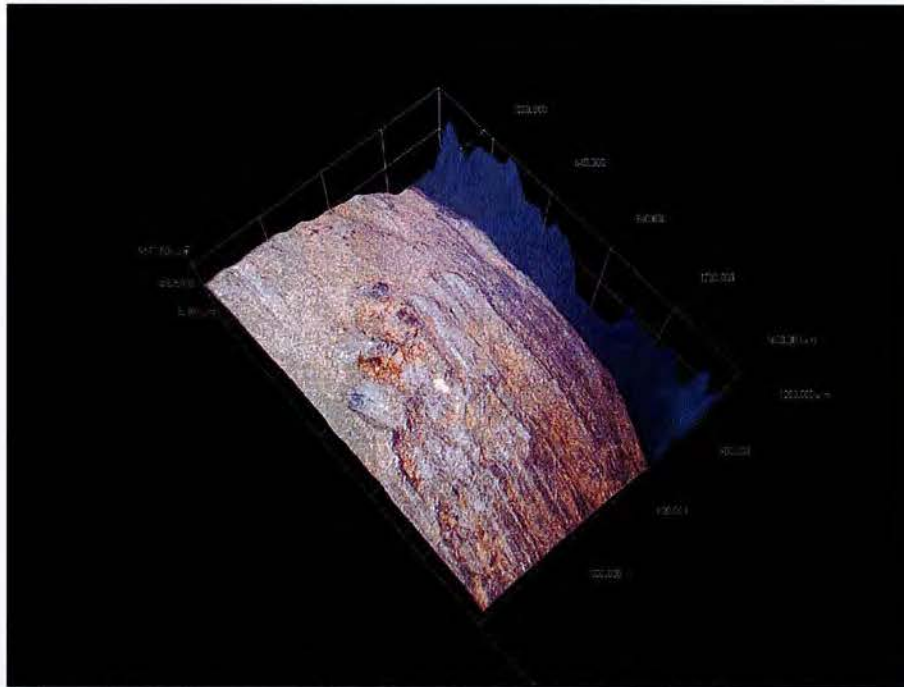


Figure 94. Ball segment, .69-caliber, showing detail of wood impact scarring.

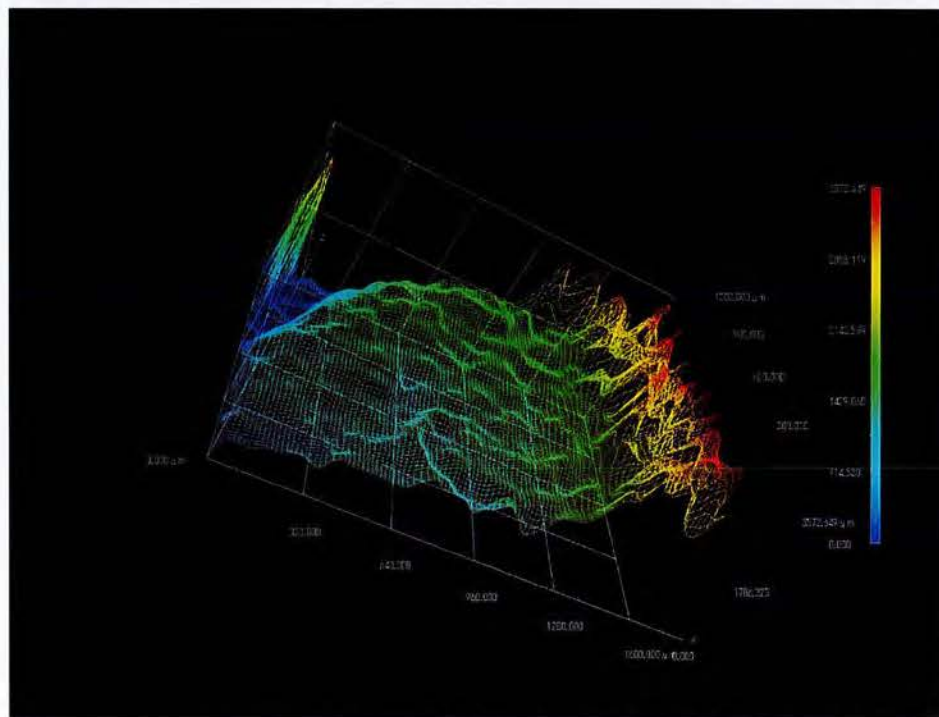


Figure 95. Wire frame model of the ball segment, .69-caliber, showing detail of wood impact scarring.

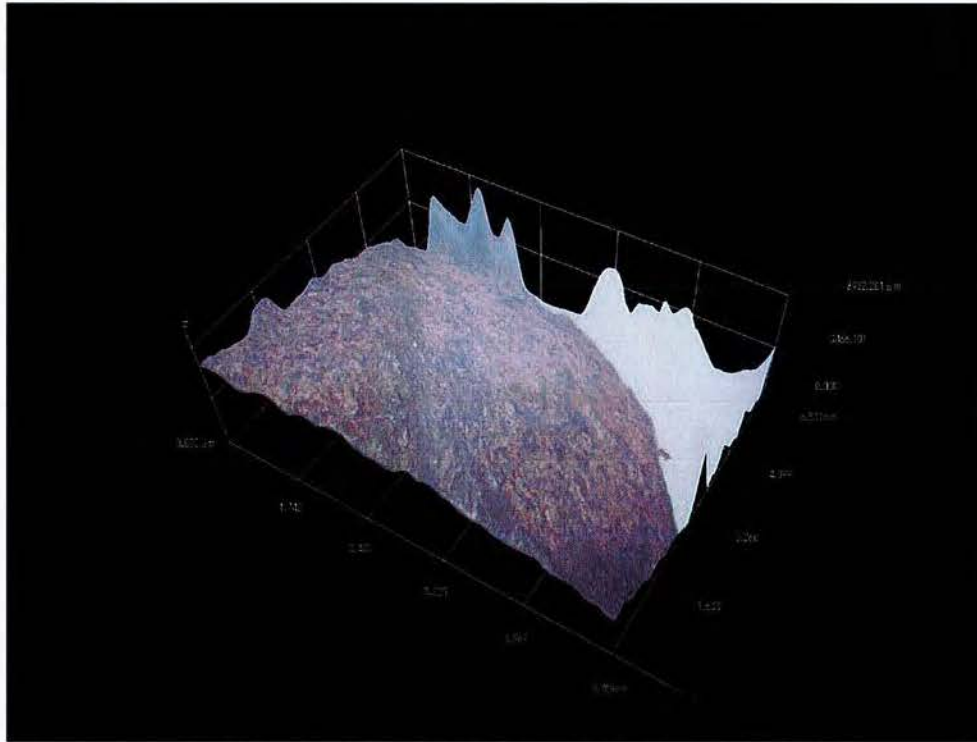


Figure 96. Fabric impressions on a .69-caliber ball segment.

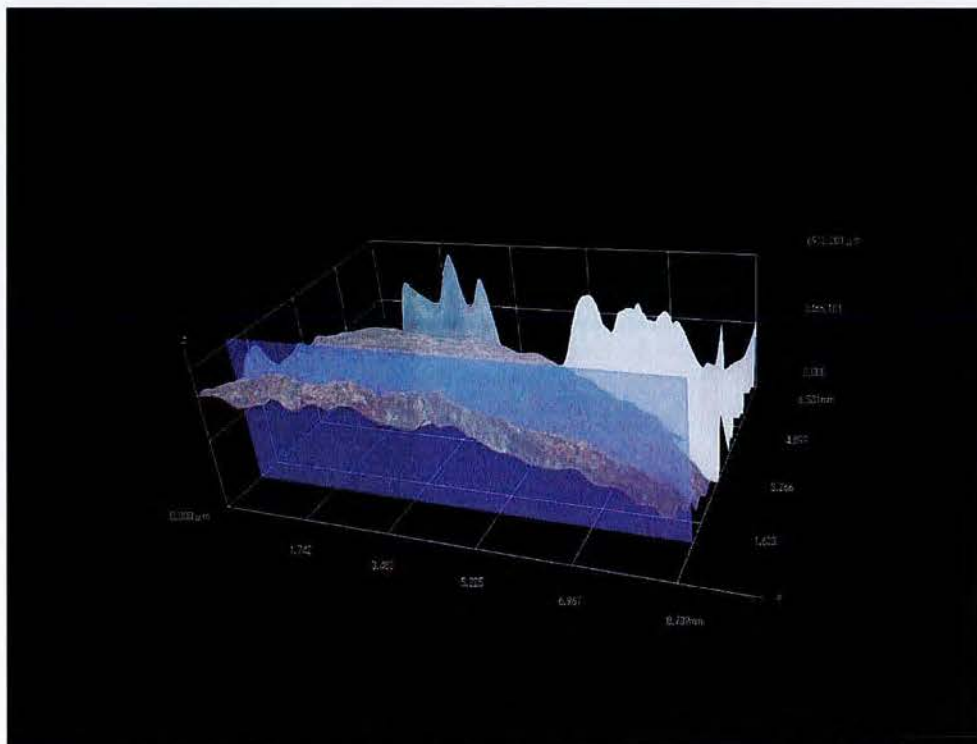


Figure 97. Profile location of the fabric impressions on the same .69-caliber ball.

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Appendix B, Blind Lead Ball Analysis Study

by Daniel M. Sivilich

One component of the live fire study identified the need to conduct a blind study of the known velocity and deformed lead balls recovered during the shooting event. Daniel Sivilich agreed to undertake the blind study as if the bullets were archaeological artifacts in need of analysis and interpretation. Mr. Sivilich is an acknowledged expert and published author (2016) on American Revolution and Colonial era bullets.

He examined the lead balls (n=31) that were:

1. fired from a known firearm
2. had a known velocity (3 exceptions)
3. have a known recovery location
4. deformation correlated with striking a known media
5. and were recovered immediately after firing by metal detecting


His analysis demonstrated that he correctly identified the bullet type, approximate caliber, and relative deformation at or above 90%. He suggested the submitted bullets were fired from at least four types of firearms based on caliber and bore characteristics engraved on the bullet during firing. In this he is essentially correct. He identified British Brown Bess caliber firearms, French caliber firearms, and two smaller bore type firearms. In fact, the live fire experiment fired seven different firearms. These can be grouped into two British Brown Bess caliber guns, two French caliber guns, and three other smaller bore firearms. These smaller bore firearms, Thomas Earle Fowler, British Artillery Carbine, and 1740 Potsdam musket used similar sized lead balls as projectiles, and do fall into two groups based on ball caliber. While the blind study could not, as expected, identify a ball as fired from a specific smoothbore musket, carbine, or fowler, the ball diameters used in the live fire experiments do fall into four distinct groups.

Mr. Sivilich's analytical techniques are those commonly used by archaeologists who analyze and interpret lead projectiles recovered in Colonial and post-Colonial sites in the United States, as well as internationally. The blind study validates the commonly employed analytical techniques and interpretations used in the study of dropped and expended ordnance from archaeological contexts.

The table shows Mr. Sivilich's blind analysis. We have inserted in the first four columns information on the actual firearm, actual ball diameter, actual velocity, and actual range of the ball recovery for comparison purposes.

LIVE FIRE MUSKET BALL EXPERIMENT - ANALYSIS BY DAN SIVILICH													
Actual gun	Actual ball dia.	Known Vel. f/s	Recovered at Range Yds.	Study No.	Weight	Calc. Dia (in)	Caliber	Height (in)	% Compression	Fabric	Estimated Velocity at Impact	Estimated Distance (yd)	
French 1766 musket - buckshot	0.292	1110	94	18A	2.0	0.2807	28						#1 Buck
French 1766 musket - buckshot	0.292	866	94	17A	2.2	0.2898	29						#1 Buck
RIFLE or SMALL BORE 1													
T. Earle Fowler - .58	0.52	1240	94	24	12.9	0.5225	52	0.504	3.5%		M	50-75	Hard target, deep scrape marks radiating out from center of impact.
T. Earle Fowler - .58	0.52	1350	94	20	13.2	0.5266	53	0.485	7.9%		M	50-75	Possibly hit hard wood or particle board, deep scrape marks radiating out from center of impact. Possible wood fragments (not very fibrous) on impact side.
T. Earle Fowler - .58	0.52	1345	94	22	13.2	0.5266	53	0.463	12.1%		M	50-75	Hit wood. Fibrous wood on impact side.
T. Earle Fowler - .58	0.52	1215	94	23	12.9	0.5225	52	0.410	21.5%		H	25-50	Deep scrape marks, probably ricochet off a rock then hit hard dirt. Small small imbedded quartz crystals.
T. Earle Fowler - .58	0.52	1285	94	21	13.0	0.5239	52	0.381	27.3%		H	25-50	Badly scraped. Possibly hit a rock or hard target then dirt. Lead folded back on non impact side.
T. Earle Fowler - .58	0.52	1240	94	25	13.0	0.5239	52	0.318	39.3%		H	25-50	Very flattened, lead slight rolled back on non impact side. Hit semi-hard target such as dry wood or hard dirt
RIFLE or SMALL BORE 2													
British Artillery Carbine - .68	0.58	1210	94	3	18.8	0.5924	59	0.563	5.0%		H	25-50	Possibly hit hard wood, deep scrape marks radiating out from center of impact. Small wood particle fragments on impact side.
T. Earle Fowler - .58	0.58	1155	25, captured in gel	31	18.1	0.5850	58	0.532	9.1%	Y	H	25-50	Fabric on impact side. Fired at target covered in fabric - fine weave impression. Ramrod mark.
British Artillery Carbine - .68	0.58	960	94	1	18.8	0.5924	59	0.475	19.8%		H	75-100	Hard target and/or clay/sand.
T. Earle Fowler - .58	0.58	no velocity data	94	26	18.0	0.5839	58	0.464	20.5%		H	50-75	Hard target, slight ricochet, sandy loam.
British Artillery Carbine - .68	0.58	1135	94	4	18.7	0.5914	59	0.453	23.4%		H	50-75	Hard target and/or clay/sand.
British Artillery Carbine - .68	0.58	1170	94	2	19.0	0.5945	59	0.425	28.5%		H	50-75	Hard target - slight ricochet off semi-hard target such as wood or tree then hit dirt.
T. Earle Fowler - .58	0.58	1460	94	30	18.0	0.5839	58	0.362	38.0%		H	25-50	Very flattened, hard dirt/compacted sand. Ricocheted off a sand bag?
T. Earle Fowler - .58	0.58	1435	94	28	19.1	0.5950	59	0.362	39.1%		H	25-50	Very flattened, hard dirt/compacted sand. Fired through a sand bag?
T. Earle Fowler - .58	0.58	1415	94	29	17.7	0.5806	58	0.325	44.0%		H	25-50	Hard target, deep scrapes radiating out from impact point. Lead rolled back, possible lead loss. Wood fibers trapped under rolled lead lip.
T. Earle Fowler - .58	0.58	no velocity data	94	27	18.0	0.5839	58	0.301	48.5%		H	25-50	Very flattened, hard dirt/compacted sand. Fired through a sand bag?

1 of 2

SMOOTH BORE 1 - POSSIBLE CHARLEVILLE													
French 1728/41 musket - .70-.71	0.626	775	94	12	23.2	0.6354	64	0.624	1.8%		L	75-100	Possible ramrod mark. Hit dirt.
French 1766 musket - .68	0.626	1090	94	13	23.1	0.6345	63	0.620	2.3%		L	75-100	Non Fibrous wood fragments on impact side. Concave indentation with scrape marks. Possible ricochet off a large pebble.
French 1728/41 musket - .70-.71	0.626	960	94	10	23.0	0.6336	63	0.612	3.4%		L	75-100	Wood fragments on impact side. Looks more like dried hardwood.
French 1766 musket - .68	0.626	785	25, captured in gel	19	22.9	0.6327	63	0.599	5.3%	Y	L	75-100	Patched, soft target (ballistic gel) or dirt. Possible ramrod mark.
French 1766 musket - .68	0.626	1110	94	18	22.7	0.6308	63	0.595	5.7%		L	75-100	Barrel band. Hit dirt. Ball and Buck.
French 1728/41 musket - .70-.71	0.626	905	94	11	23.1	0.6345	63	0.586	7.6%		L	75-100	Hit hard dirt. Concave indentation with scrape marks. Possible ricochet off a large pebble.
French 1766 musket - .68	0.626	865	94	17	23.1	0.6345	63	0.537	15.4%		H	25-50	Hit hard dirt. Imbedded micro crystalline quartz. Concave depression with no scrape marks. Possible ramrod mark. Ball and Buck
Firearm not known - prob. French	0.626	no velocity data	94	32	22.5	0.6290	63	0.523	16.9%		H	25-50	Hit a tree or wood - much wood fiber still on ball.
French 1766 musket - .68	0.626	1215	94	15	23.2	0.6354	64	0.518	18.5%		H	25-50	Slight ricochet. Hit hard dirt. Concave indentation with scrape marks. Possible ricochet off a large pebble.
French 1766 musket - .68	0.626	1175	94	16	23.5	0.6382	64	0.513	19.6%		H	25-50	Hard target and/or claysand. Faint barrel band.
French 1766 musket - .68	0.626	1205	94	14	23.1	0.6345	63	0.499	21.4%		H	25-50	Hard target and/or claysand. Ricochet. Faint cut line across non impact hemisphere
SMOOTH BORE 2 - POSSIBLE BROWN BESS													
British 1756 Long Land musket - .76	0.69	630	25, captured in gel	9	31.3	0.7022	70	0.664	5.4%	Y	L	75-100	Patched, soft target or dirt.
British 1756 Long Land musket - .76	0.69	600	94	8	31.5	0.7036	70	0.651	7.5%	Y	L	75-100	Patched, light scrapes radiating out from impact point. Hard target and/or claysand. Barrel band.
British 1742 Long Land musket - .76	0.69	870	94	5	31.7	0.7051	71	0.619	12.2%		M	50-75	Hard target and/or claysand.
British 1756 Long Land musket - .76	0.69	1240	25	7	31.2	0.7014	70	0.591	15.7%		M	25-50	Hard target. Concave depression with rough cross hatch pattern, deep scrape marks radiating out from depression.
British 1756 Long Land musket - .76	0.69	no velocity data	94	6	32.0	0.7073	71	0.577	18.4%	WIRE	M	25-50	Concave depression and 0.050" (approx) diameter wire impression on impact side. White particles suggest this hit a piece of wood.
Diameter calculated with Sivilich Formula													
"Caliber" is the calculated diameter * 100 and rounded up to a whole number													
													

Appendix C

Elemental Analysis of Modern Lead Shot

By Daniel T. Elliott, The LAMAR Institute, Savannah, Georgia 2017

Elemental analysis is a useful approach for the archaeological study of early ammunition. The present study examined modern examples of round lead balls, similar to those used in the ballistics study.

A sample of seven modern lead shot were analyzed. These shot measured .28, .31, .51, .58, .62, .66 and .67 calibers. This analysis was conducted at the Elliott's Archaeology Laboratory in Rincon, Georgia. Each sample was measured for 180 seconds using a Bruker Tracer. The methods employed were identical to those currently being used to analyze archaeological examples, following the advice of Bruce Kaiser. The composite spectrograms of these seven samples is shown in Figure 1. Results for individual samples are shown in Tables 2-8.

Figure 2 shows an enlargement of the composite spectrogram for the elements Cadmium, Tin and Antimony. Each of these elements is present in low quantities, but they are present. Previous study of archaeological examples from 18th century collections indicate that Tin and Antimony are sensitive indicators of possible cultural significance. The interpretation of these indications are currently under consideration by researchers.

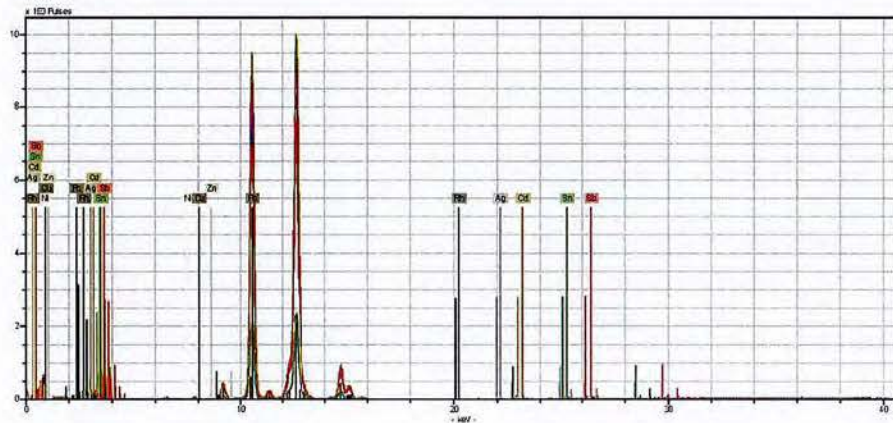


Figure 1. Composite of Seven Spectrograms.

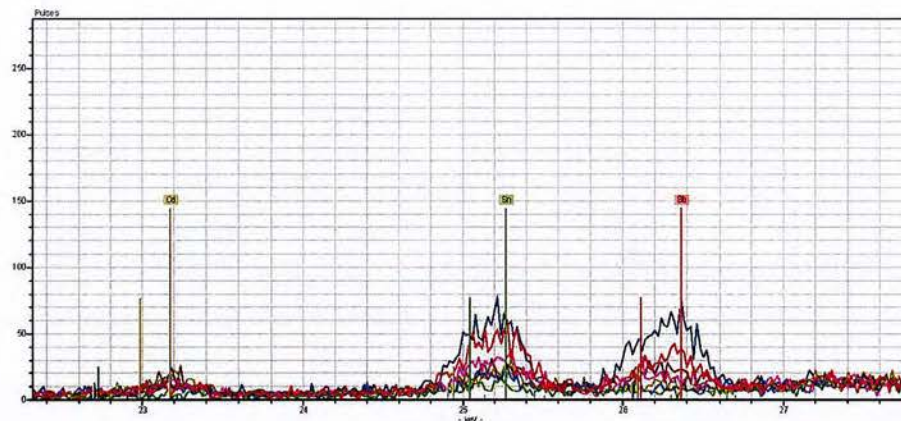


Figure 2. Enlargement of Composite Spectrograms, Showing Elements Cadmium, Tin and Antimony.

Table 1. Photon Energies from Seven Modern Balls.

Sample	Ag K12	Ag L1	Cd K12	Cd L1	Cu K12	Ni K12	Pb L1	Pb M1	Rb K12	Rh K12	Rh L1	Sb K12	Sb L1	Sn K12	Sn L1	Zn K12	Zr K12
28 cal	100	1	144	0	189	112	85542	788	108	75	6	483	64	927	3	2	249
31 cal	79	19	30	0	117	50	27076	228	1	30	0	5	14	121	9	9	89
51 cal	90	1	164	-5	249	116	105003	913	88	107	0	212	67	554	-4	21	351
58 cal	70	10	143	0	186	61	93385	722	102	38	0	26	26	262	18	26	298
62 cal	66	1	179	0	357	104	102789	871	1	23	0	1085	42	1106	35	53	268
66 cal	60	20	203	0	308	94	109591	961	235	15	0	276	41	318	25	0	328
69 cal	82	21	265	0	327	92	116861	970	140	84	0	93	40	307	2	59	358



ARTAX - ELEMENT ANALYSIS

Listed at 4/12/2017 5:47:25 PM

Serial number:	Project:
Spectrum: Bohy1@070417_122539	Meas.date: 4/7/2017 10:15:19 AM
Method: Lead2 (Bayes)	Live time: 162 s
Count rate: 2145 cps	Dead time: 0.1 %
Voltage: 45 kV	Current: 20 µA
Anode:	Filter: Ti/Al
Optic:	Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
Mn	K12	0.00	53	176
Fe	K12	0.00	154	191
Co	K12	0.00	52	224
Ni	K12	0.00	92	253
Cu	K12	0.00	327	269
Zn	K12	0.00	59	261
Ga	K12	0.00	768	436
Rb	K12	0.00	140	1494
Sr	K12	0.00	169	530
Y	K12	0.00	2234	1051
Zr	K12	0.00	358	400
Rh	K12	0.00	84	41
Rh	L1	0.00		397
Ag	K12	0.00	82	95
Ag	L1	0.00	21	349
Cd	K12	0.00	265	126
Cd	L1	0.00		321
Sn	K12	0.00	307	225
Sn	L1	0.00	2	267
Sb	K12	0.00	93	294
Sb	L1	0.00	40	263
Pb	L1	0.00	116861	1344
Pb	M1	0.00	970	454



ARTAX - ELEMENT ANALYSIS

Listed at 4/12/2017 5:47:43 PM

Serial number:	Project:
Spectrum: Bohy2-001@070417_122539	Meas.date: 4/7/2017 10:23:09 AM
Method: Lead2 (Bayes)	Live time: 163 s
Count rate: 2042 cps	Dead time: 0.1 %
Voltage: 45 kV	Current: 20 µA
Anode:	Filter: Ti/Al
Optic:	Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
Mn	K12	0.00	20	192
Fe	K12	0.00	117	178
Co	K12	0.00	12	207
Ni	K12	0.00	94	260
Cu	K12	0.00	308	292
Zn	K12	0.00		289
Ga	K12	0.00	676	457
Rb	K12	0.00	235	1416
Sr	K12	0.00	148	527
Y	K12	0.00	1911	994
Zr	K12	0.00	328	378
Rh	K12	0.00	15	65
Rh	L1	0.00		353
Ag	K12	0.00	60	126
Ag	L1	0.00	20	295
Cd	K12	0.00	203	156
Cd	L1	0.00		271
Sn	K12	0.00	318	309
Sn	L1	0.00	25	267
Sb	K12	0.00	276	407
Sb	L1	0.00	41	285
Pb	L1	0.00	109591	1233
Pb	M1	0.00	961	420



ARTAX - ELEMENT ANALYSIS

Listed at 4/12/2017 5:47:58 PM

Serial number:	Project:
Spectrum: Bohy3@070417_122539	Meas.date: 4/7/2017 10:30:38 AM
Method: Lead2 (Bayes)	Live time: 163 s
Count rate: 1949 cps	Dead time: 0.1 %
Voltage: 45 kV	Current: 20 µA
Anode:	Filter: Ti/Al
Optic:	Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
Mn	K12	0.00	76	155
Fe	K12	0.00	173	169
Co	K12	0.00	14	198
Ni	K12	0.00	104	237
Cu	K12	0.00	357	282
Zn	K12	0.00	53	250
Ga	K12	0.00	562	377
Rb	K12	0.00	1	1327
Sr	K12	0.00	139	482
Y	K12	0.00	1817	975
Zr	K12	0.00	268	394
Rh	K12	0.00	23	56
Rh	L1	0.00		376
Ag	K12	0.00	66	121
Ag	L1	0.00	1	329
Cd	K12	0.00	179	168
Cd	L1	0.00		304
Sn	K12	0.00	1106	364
Sn	L1	0.00	35	284
Sb	K12	0.00	1085	426
Sb	L1	0.00	42	298
Pb	L1	0.00	102789	1191
Pb	M1	0.00	871	433



ARTAX - ELEMENT ANALYSIS

Listed at 4/12/2017 5:48:11 PM

Serial number:	Project:
Spectrum: Bohy4@070417_122539	Meas.date: 4/7/2017 10:35:36 AM
Method: Lead2 (Bayes)	Live time: 165 s
Count rate: 1727 cps	Dead time: 0.1 %
Voltage: 45 kV	Current: 20 µA
Anode:	Filter: Ti/Al
Optic:	Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
Mn	K12	0.00	53	143
Fe	K12	0.00	135	160
Co	K12	0.00	1	188
Ni	K12	0.00	61	237
Cu	K12	0.00	186	273
Zn	K12	0.00	26	277
Ga	K12	0.00	679	400
Rb	K12	0.00	102	1120
Sr	K12	0.00	121	429
Y	K12	0.00	1591	913
Zr	K12	0.00	298	341
Rh	K12	0.00	38	41
Rh	L1	0.00		328
Ag	K12	0.00	70	94
Ag	L1	0.00	10	293
Cd	K12	0.00	143	128
Cd	L1	0.00		270
Sn	K12	0.00	262	212
Sn	L1	0.00	18	249
Sb	K12	0.00	26	307
Sb	L1	0.00	26	258
Pb	L1	0.00	93385	1043
Pb	M1	0.00	722	388



ARTAX - ELEMENT ANALYSIS

Listed at 4/12/2017 5:48:35 PM

Serial number:	Project:
Spectrum: Bohy5@070417_122539	Meas.date: 4/7/2017 10:39:44 AM
Method: Lead2 (Bayes)	Live time: 164 s
Count rate: 1906 cps	Dead time: 0.1 %
Voltage: 45 kV	Current: 20 µA
Anode:	Filter: Ti/Al
Optic:	Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
Mn	K12	0.00	66	162
Fe	K12	0.00	112	160
Co	K12	0.00	53	175
Ni	K12	0.00	116	203
Cu	K12	0.00	249	262
Zn	K12	0.00	21	297
Ga	K12	0.00	783	448
Rb	K12	0.00	88	1267
Sr	K12	0.00	125	463
Y	K12	0.00	1790	979
Zr	K12	0.00	351	384
Rh	K12	0.00	107	21
Rh	L1	0.00		377
Ag	K12	0.00	90	104
Ag	L1	0.00	1	330
Cd	K12	0.00	164	149
Cd	L1	0.00		307
Sn	K12	0.00	554	230
Sn	L1	0.00		264
Sb	K12	0.00	212	307
Sb	L1	0.00	67	268
Pb	L1	0.00	105003	1153
Pb	M1	0.00	913	421



ARTAX - ELEMENT ANALYSIS

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Serial number:	Project:
Spectrum: Bohy6@070417_122539	Meas.date: 4/7/2017 10:45:55 AM
Method: Lead2 (Bayes)	Live time: 175 s
Count rate: 562 cps	Dead time: 0.0 %
Voltage: 45 kV	Current: 20 µA
Anode:	Filter: Ti/Al
Optic:	Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
Mn	K12	0.00	43	68
Fe	K12	0.00	54	58
Co	K12	0.00	16	66
Ni	K12	0.00	50	79
Cu	K12	0.00	117	92
Zn	K12	0.00	9	92
Ga	K12	0.00	182	117
Rb	K12	0.00	1	377
Sr	K12	0.00	51	133
Y	K12	0.00	554	255
Zr	K12	0.00	89	114
Rh	K12	0.00	30	23
Rh	L1	0.00		232
Ag	K12	0.00	79	68
Ag	L1	0.00	19	219
Cd	K12	0.00	30	82
Cd	L1	0.00		207
Sn	K12	0.00	121	183
Sn	L1	0.00	9	181
Sb	K12	0.00	5	268
Sb	L1	0.00	14	182
Pb	L1	0.00	27076	331
Pb	M1	0.00	228	280



ARTAX - ELEMENT ANALYSIS

Listed at 4/12/2017 5:44:54 PM

Serial number:

Spectrum: Bohy7@070417_122539

Method: Lead2 (Bayes)

Count rate: 1580 cps

Voltage: 45 kV

Anode:

Optic:

Project:

Meas.date: 4/7/2017 10:58:39 AM

Live time: 166 s

Dead time: 0.1 %

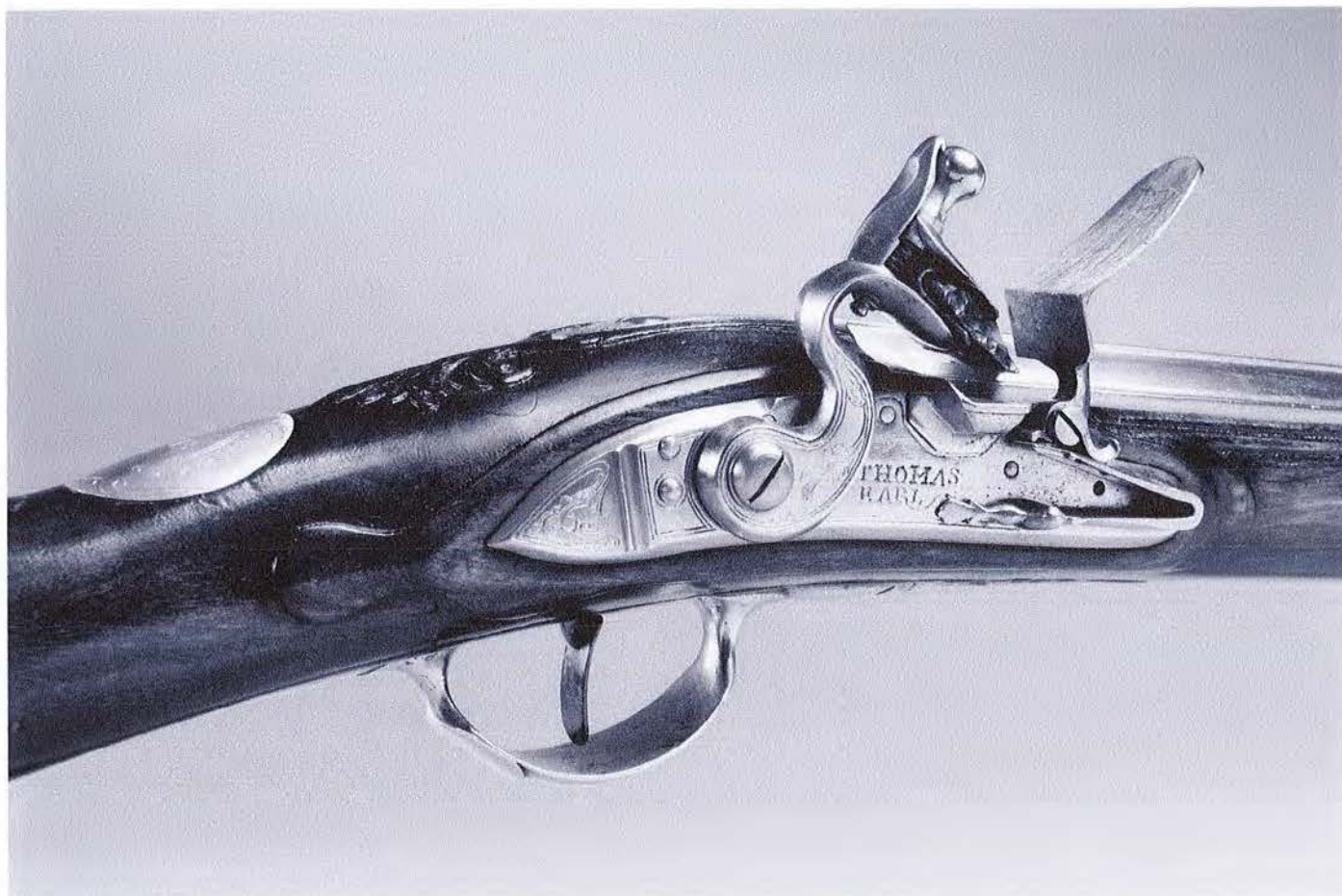
Current: 20 µA

Filter: Ti/Al

Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
Mn	K12	0.00	61	145
Fe	K12	0.00	72	138
Co	K12	0.00	29	134
Ni	K12	0.00	112	168
Cu	K12	0.00	189	229
Zn	K12	0.00	2	255
Ga	K12	0.00	585	350
Rb	K12	0.00	108	1079
Sr	K12	0.00	155	351
Y	K12	0.00	1428	764
Zr	K12	0.00	249	314
Rh	K12	0.00	75	36
Rh	L1	0.00	6	318
Ag	K12	0.00	100	74
Ag	L1	0.00	1	264
Cd	K12	0.00	144	118
Cd	L1	0.00		253
Sn	K12	0.00	927	284
Sn	L1	0.00	3	242
Sb	K12	0.00	483	386
Sb	L1	0.00	64	248
Pb	L1	0.00	85542	947
Pb	M1	0.00	788	392

EXHIBIT 3



SHOOTING THE PAST: COLONIAL & REVOLUTIONARY WAR FIREARM LIVE FIRE EXPERIMENTS & SPHERICAL BALL PERFORMANCE.

By Joel Bohy

During the Parker's Revenge Archaeology Project at Minute Man National Historical Park in 2016, archaeologist Dr. Douglas Scott, well known for his work at The Little Big Horn and other historic battlefields, mentioned how we were finding great examples of fired Provincial and British ball to put the historical study in context, but wouldn't it be great to do a live fire study of flintlock firearms used during the Revolutionary War to really expand our knowledge of how these guns actually functioned and try to acquire data that might not only help conflict archaeologists, but also those who study and own the original flintlock firearms? I also felt that it could broaden our understanding of important historic events and how they transpired. fifteen years previous, I had begun collecting custom-built examples of these firearms to shoot live. We then had the tools to make the study happen. Since this was self-funded, we needed to raise some money. The Modern Heritage Foundation gave us a grant which enabled us to hire a

ballistics specialist, Nathan Boor from Aimed Research. He would bring hi-speed cameras and the computer equipment necessary for us to capture the scientific data. The rest of the study would be paid for by us.

Prior to our testing we studied original paper cartridges to get the correct range of laid paper weights for our loads. We also found the correct weight linen cord to tie them off. Ball in a variety of calibers was purchased (Figure 1), ballistics gelatin, as well as making up cloth samples to simulate civilian and military clothing of the period was obtained. The cloth used was custom reproduced in England to 18th century specifications, as were the linings and Irish linen for the shirting. As propellant, we studied a variety of available modern black powder and decided that Swiss brand in FF grain size would be our standard. A range safety officer was designated and dates were set.

In November 2016, we met at a private property just south of Atlanta, Georgia, to commence the study. For the first phase of the project, we had a target setup at 100 yards (although determining accuracy was not our initial goal) for an aiming point, and the camera equipment was setup to capture muzzle velocity. A wooden palisade made from a variety of wood species was built as a backstop as well as a dirt berm. We narrowed down the analysis to seven guns, a British Royal Artillery carbine, British Pattern 1742 and 1756 long land, a French Pattern 1728/41 musket, a French Pattern 1768 musket, a Potsdam Model 1740 musket, and a Thomas Earle Worcester County-style fowler (Figure 2). The two British long land pattern muskets were a bit redundant as the shape of the lock and stock would not make a difference in ballistics but we were having some issues with the 1756. After firing each round, the range was cleared and a recovery team metal detected to find the fired ball, which was then bagged, numbered, and recorded for later study.

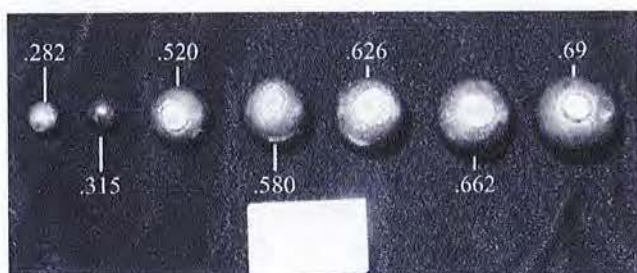


Figure 1. Cast lead balls, .282, .315, .520, .580, .626, .662, and .69 caliber.



Figure 2. Bill Rose and Dr. Douglas Scott reviewing the bore diameters before loading.

The second phase of the study was to fire into ballistics gelatin at 25 yards with cloth samples of a variety of types on the face, collect the ball, and see what data that could give (Figure 3). Previously on Revolutionary War conflict archaeology sites, ball had been found with a cloth imprint that some believed was from patching. The deformation of that ball was on the face where they struck the target and under magnification, powder burn and stippling could be seen on the opposite side of the ball which meant that there had been no patch behind it so the cloth weave on the struck face of the

ball had to have come from initially hitting a cloth target. This was also tested by not using a paper cartridge and using a cloth patch when firing the ball. The results of the cloth patch while shooting into the gelatin showed plain woven broadcloth on the struck face as well as some light deformation (Figure 4), no patch weave and no powder burn/stippling on the back as the patch had taken the brunt of the powder ignition. Either way we fired, the weave of the cloth that was initially struck by the ball was clearly visible and when fired at a finer woven cloth, the difference in weave was clearly visible. This meant that the type of cloth the ball struck could be determined by the imprint on the ball.

We also learned some data about accuracy, although again, that was not the initial goal of the study. The Worcester County-style fowler was the first gun fired. We did ten shots per gun but switched shooters after five rounds. The fowler was determined to be the most accurate weapon of the group. At 100 yards every shot hit the target. It also had the highest muzzle velocity of them all averaging at about 1300 f/s. The Potsdam Pattern 1740 was the worst with very few ball recoveries and an average muzzle velocity of 700 f/s.

While we covered more ground with this study than expected there are many more questions to be answered with live fire of historic arms. This past November, we continued with another week of study that gave us some new and important data on flint-lock firearms as well as some percussion. Hopefully this will be published in the near future.



Figure 3. Bill Rose firing the Thomas Earle fowler at cloth-covered ballistics gelatin.

So why was this study important? We were able to use the data from the recovered ball to form a deformation index for use by conflict archaeologists. They can use the index to come up with a likely muzzle velocity as well as the distance from the muzzle of the gun that fired the ball. At the Fields of Conflict Archaeology Conference this past fall, I saw many papers and posters that had used our work to help tell the story of the battles they had been studying. Soon after we completed the first week of work, we were asked by the National Park Service Northeast Region Archaeology Program to volunteer on a metallic survey of sample areas at Little Round Top in Gettysburg prior to a controlled vegetation removal burn they were going to do. While surveying an area where a temporary mass grave had been, we recovered a few interesting balls. Two had been chewed out of bodies by hogs, but one had a cloth imprint on it that we could match up based upon the ballistics study to a twill woven cloth, possibly a fatigue blouse or kersey trousers. This makes all of the time and expense worthwhile to see

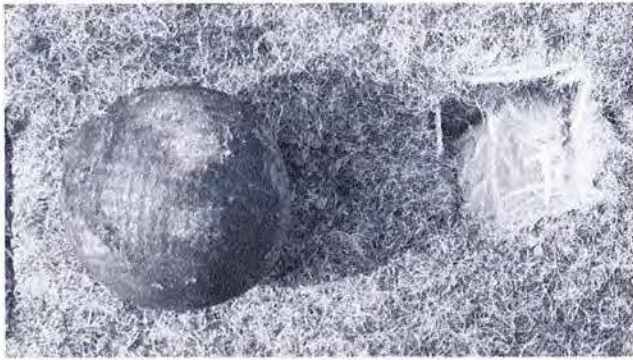


Figure 4. Ball with a plain woven cloth imprint retrieved from the ballistics gelatin.

our study used in this manner and hopefully our future firearms studies will yield other data that might prove invaluable to archaeologists, historians, and gun collectors alike.

To learn more about this study see the following report on the project:

Scott, D.D., Bohy, J., Boor, N., Haecker, C., Rose, W. Severts, P. 2017. Colonial era firearm bullet performance: a live fire experimental study for archaeological interpretation. Found at:

<http://modernheritage.net/research.html>

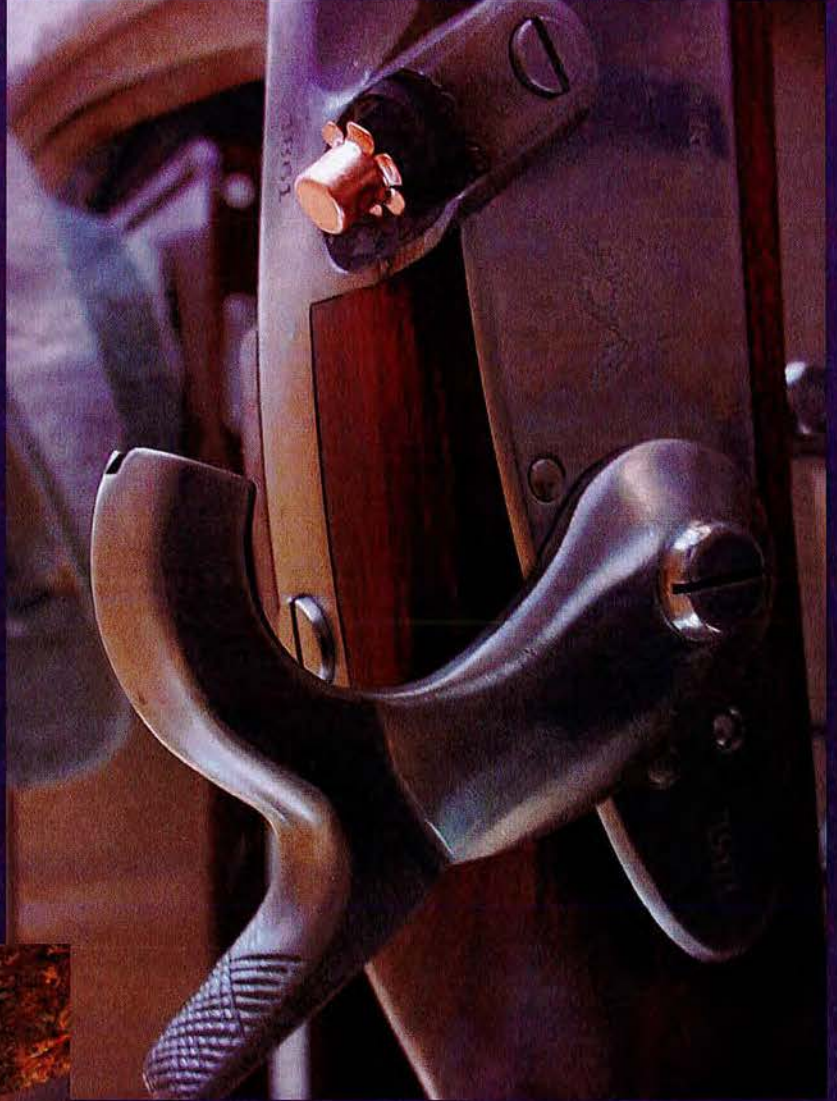


What Happens When a Gun Goes Off: Flintlock, Percussion Cap, and Metallic Cartridge Blackpowder Weapons

Douglas Scott, PhD, RPA, Colorado Mesa University;
AFTE Technical Advisor
Contact: ddscott@coloradomesa.edu



Flintlock – Colonial Fowler



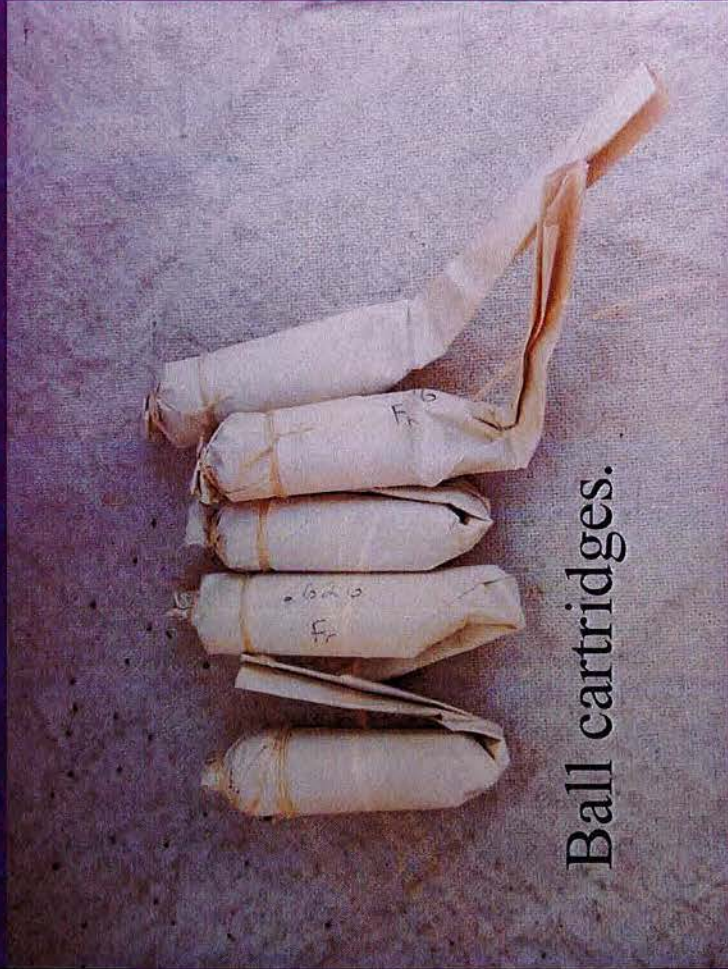
Percussion Cap – Civil War Rifled Musket, Courtesy Luke Haag, FSSI.

Flintlock Ignition System: Loading and Live Fire Examples

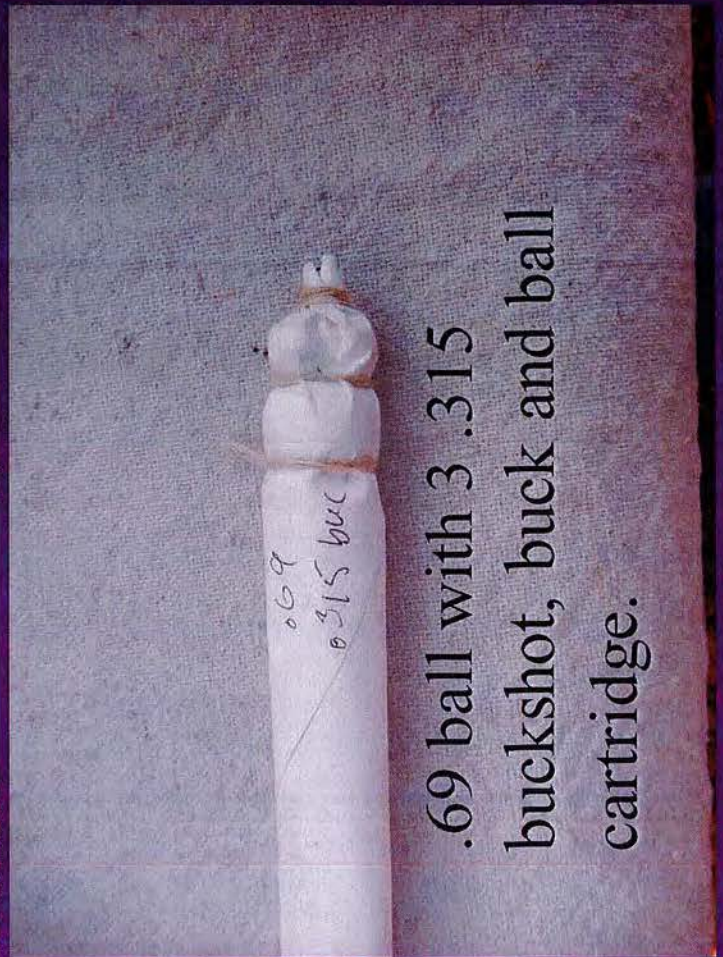
Colonial Flintlocks – modern reproductions of
common Revolutionary War guns.



Cast lead balls, .282, .315, .520, .580,
.626, .662, and .69.

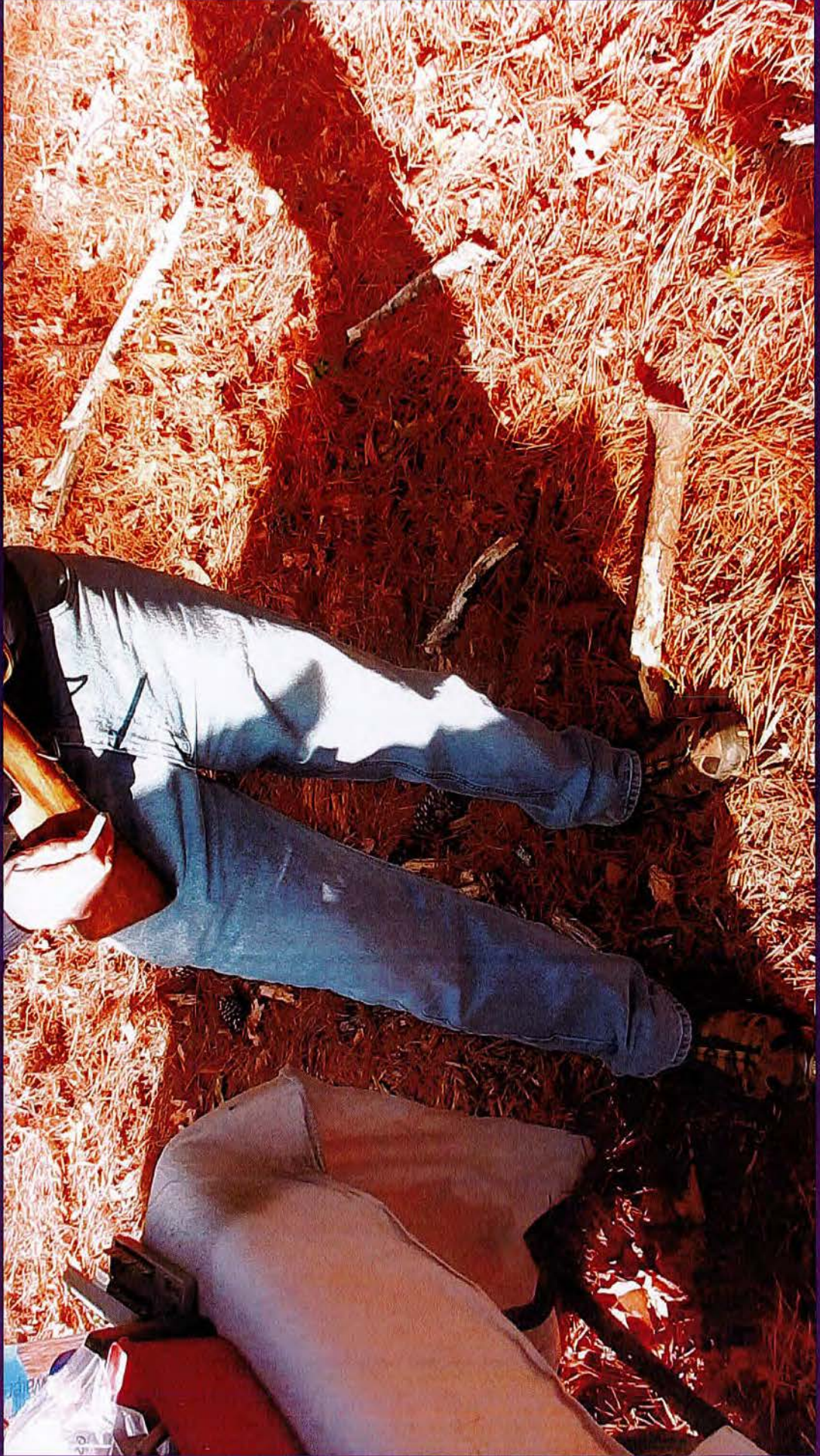


Ball cartridges.



.69 ball with 3 .315
buckshot, buck and ball
cartridge.

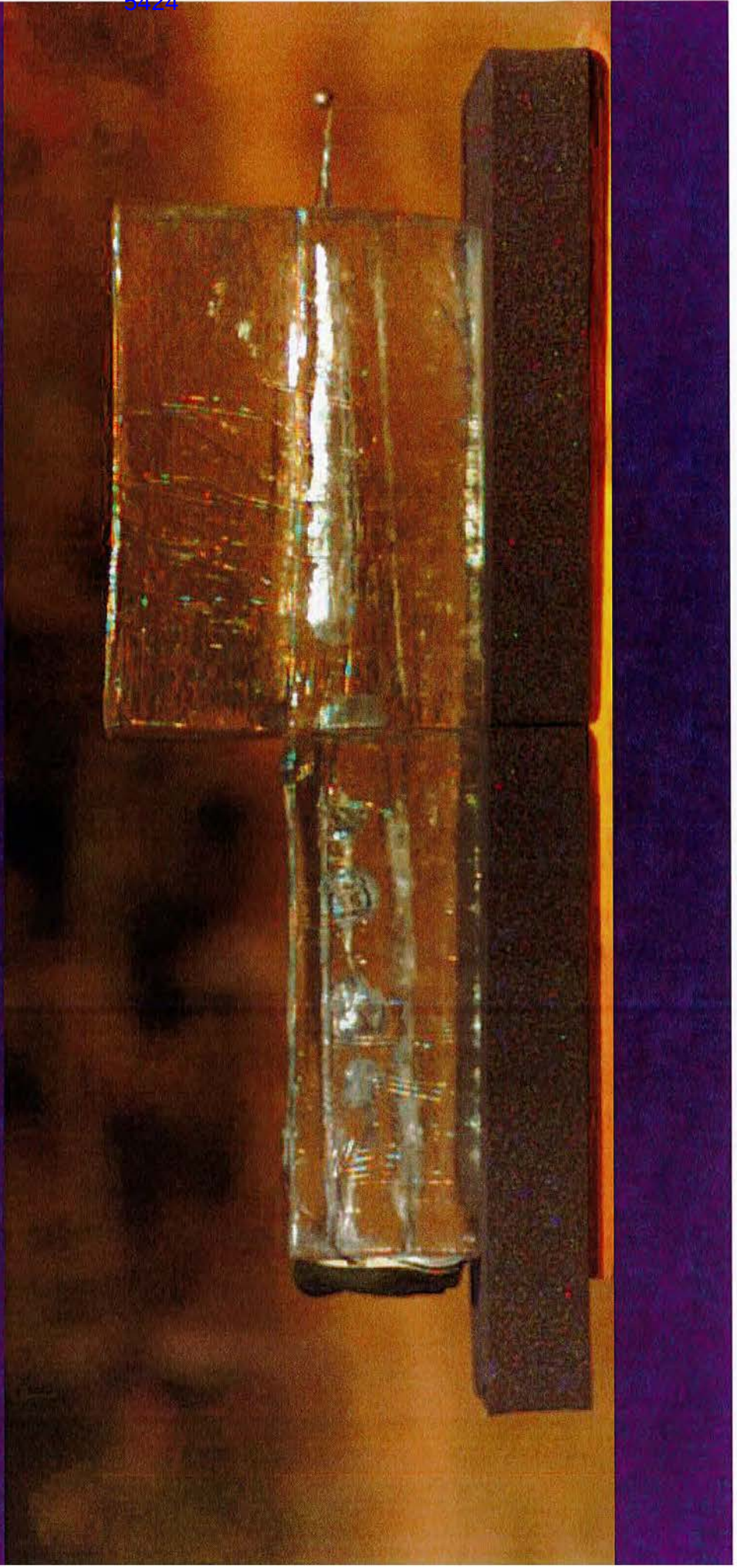
Flintlock loading sequence: Prime the pan, close the steel or frizzen, load the charge, and ram home the ball. With prepared cartridges soldiers were expected to fire at least 3 rounds per minute.



Live Fire – 1756 Long Land Pattern British Musket, actual
elapsed time – 0.4 second to full recoil

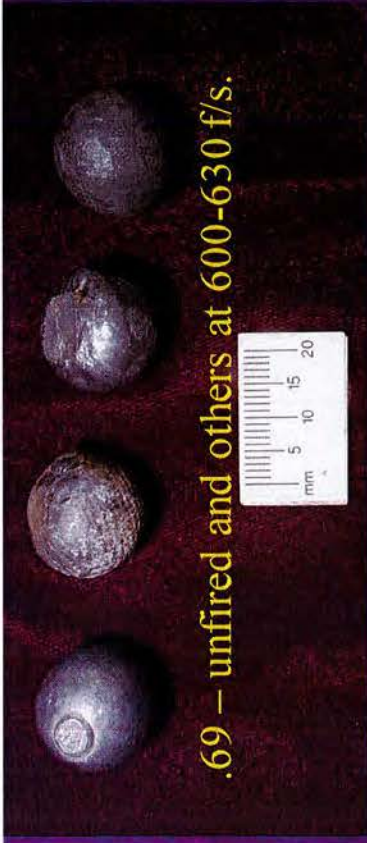


French M1766 Musket, .626 ball, 364.82 grains, 110 grain charge less 10 grains for priming. Velocity in 1025 f/s, passes through uniform cloth thickness, 32 inches Clear Ballistic gel, exits as velocity of 280 f/s. Range 25 yards.

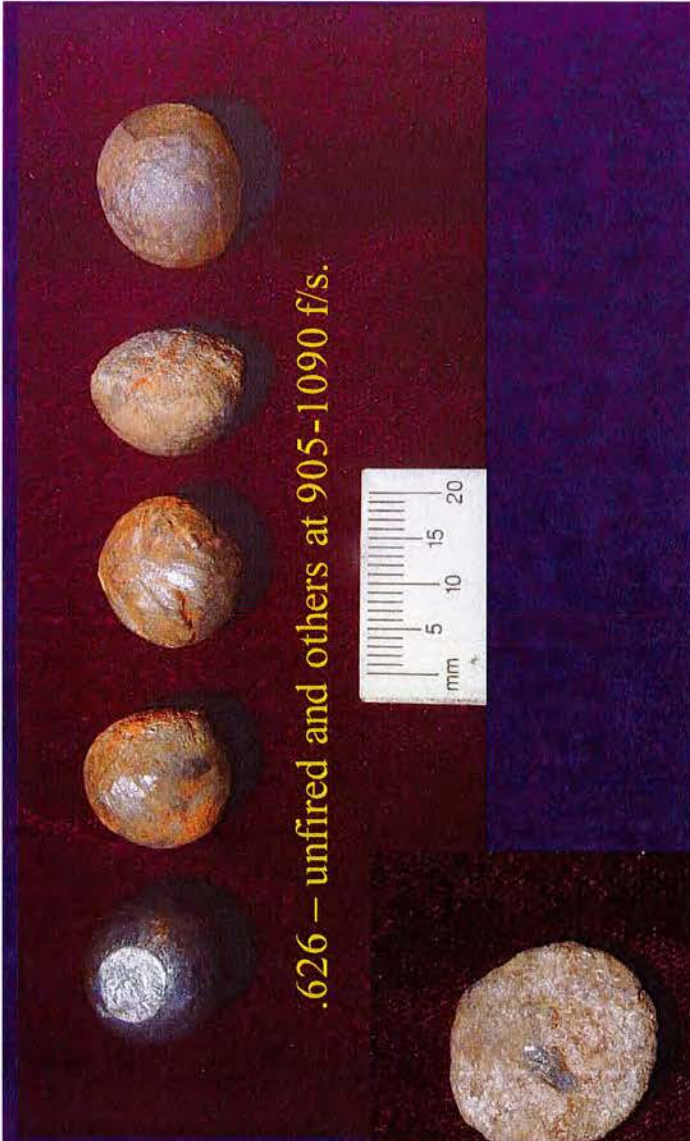


British prismatic flints (black, L. unfired, R. expended after 20 shots, and French spall flint, unfired.





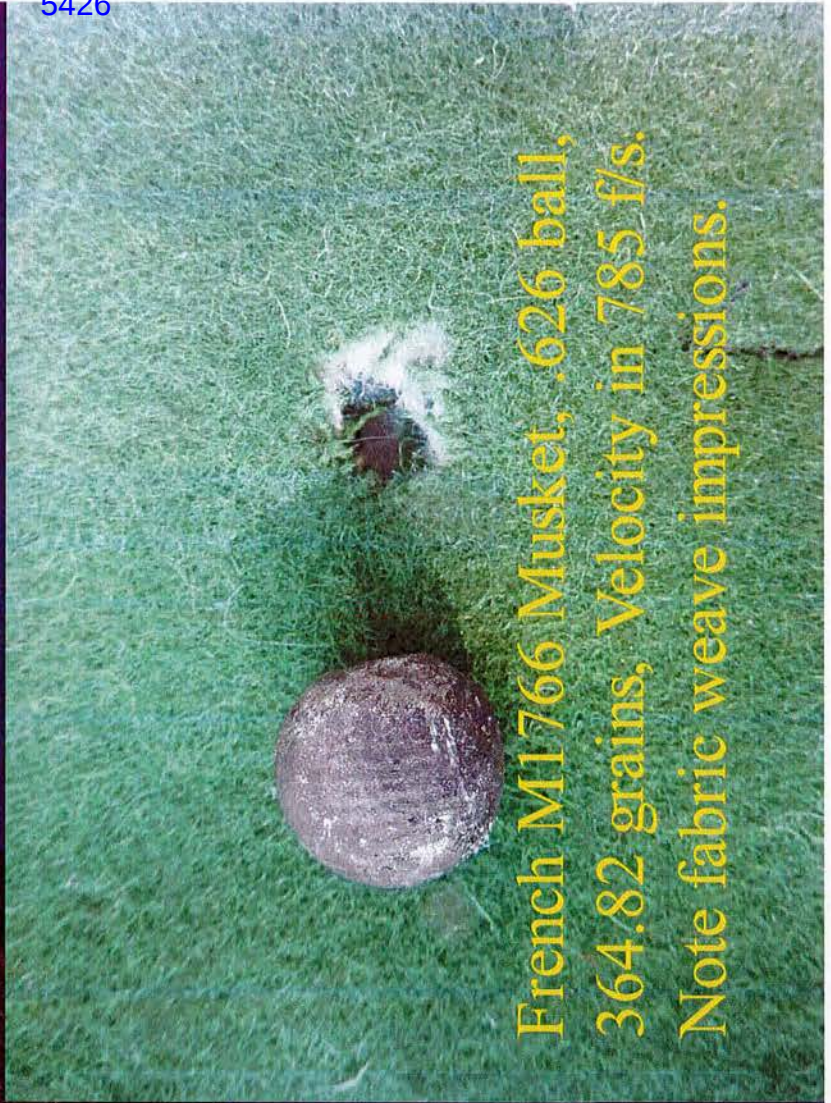
.69 – unfired and others at 600-630 f/s.



.626 – unfired and others at 905-1090 f/s.



.580 – unfired and others at 1415-1480 f/s.

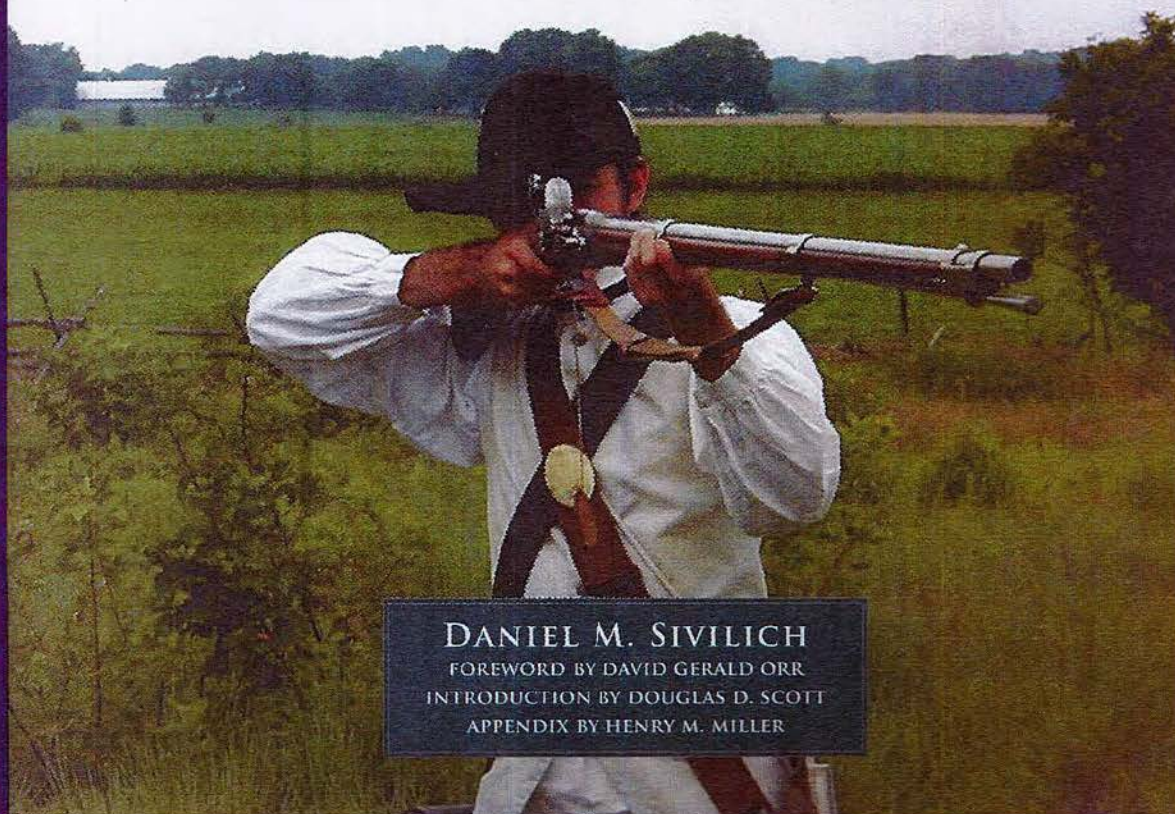


French M1766 Musket, .626 ball,
364.82 grains, Velocity in 785 f/s.
Note fabric weave impressions.



MUSKET BALL AND SMALL SHOT IDENTIFICATION

A GUIDE



DANIEL M. SIVILICH

FOREWORD BY DAVID GERALD ORR

INTRODUCTION BY DOUGLAS D. SCOTT

APPENDIX BY HENRY M. MILLER

Reference:

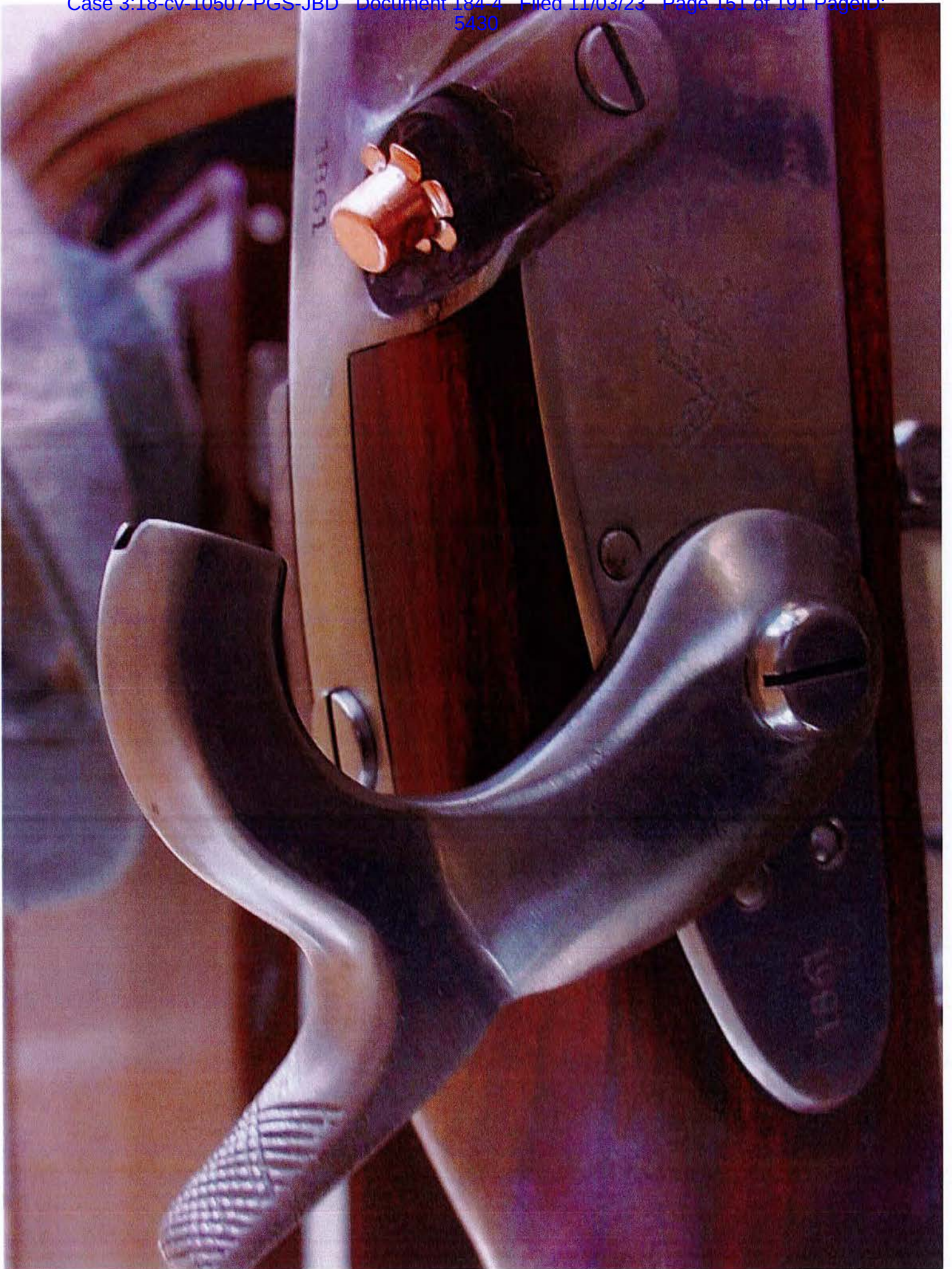
Scott, Douglas D., Joel Bohy, Nathan Boor, Charles
Haecker, William Rose, and Patrick Severts
2017 Colonial Era Firearm Bullet Performance: A Live
Fire Experimental Study for Archaeological
Interpretation.

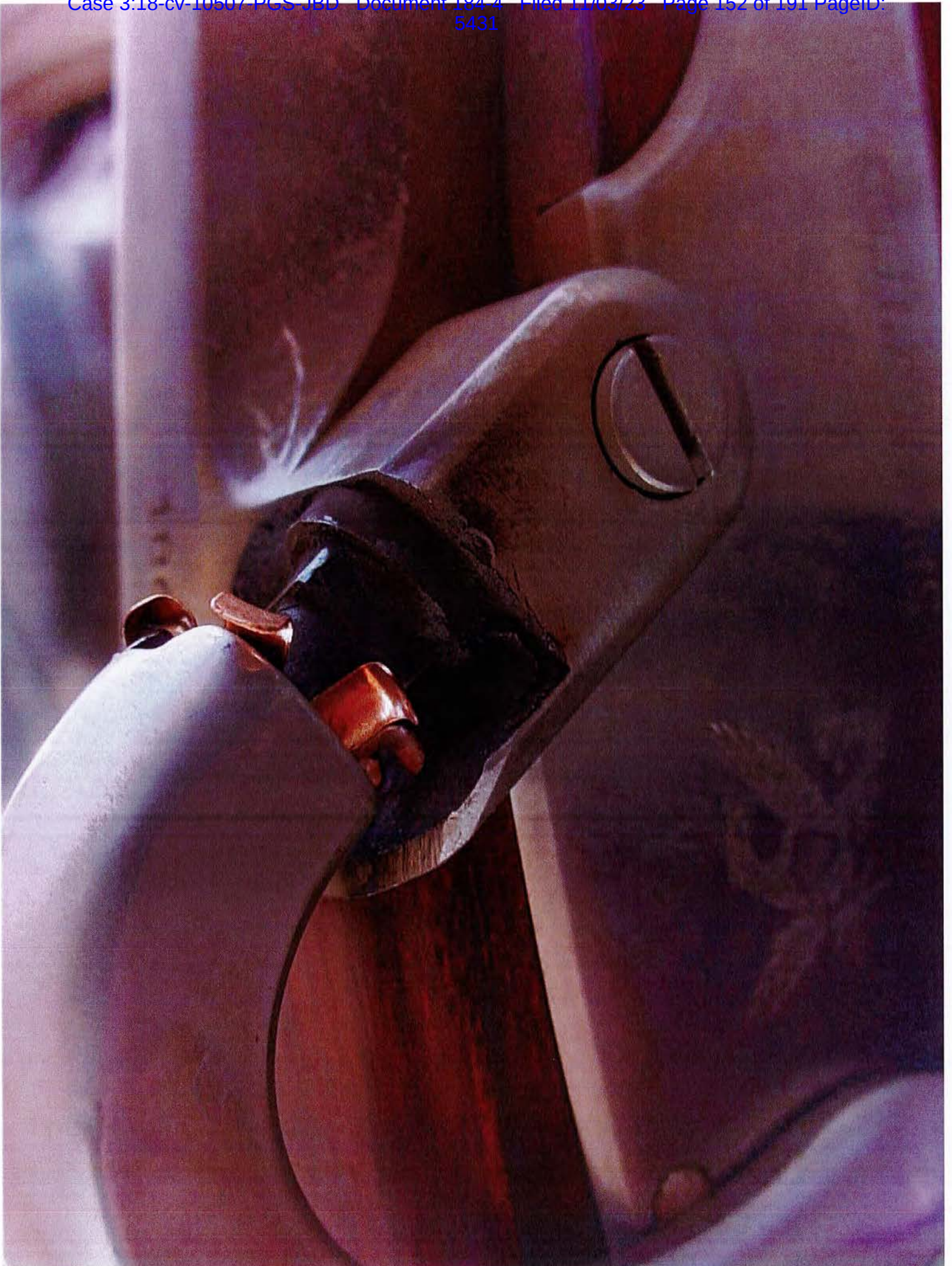
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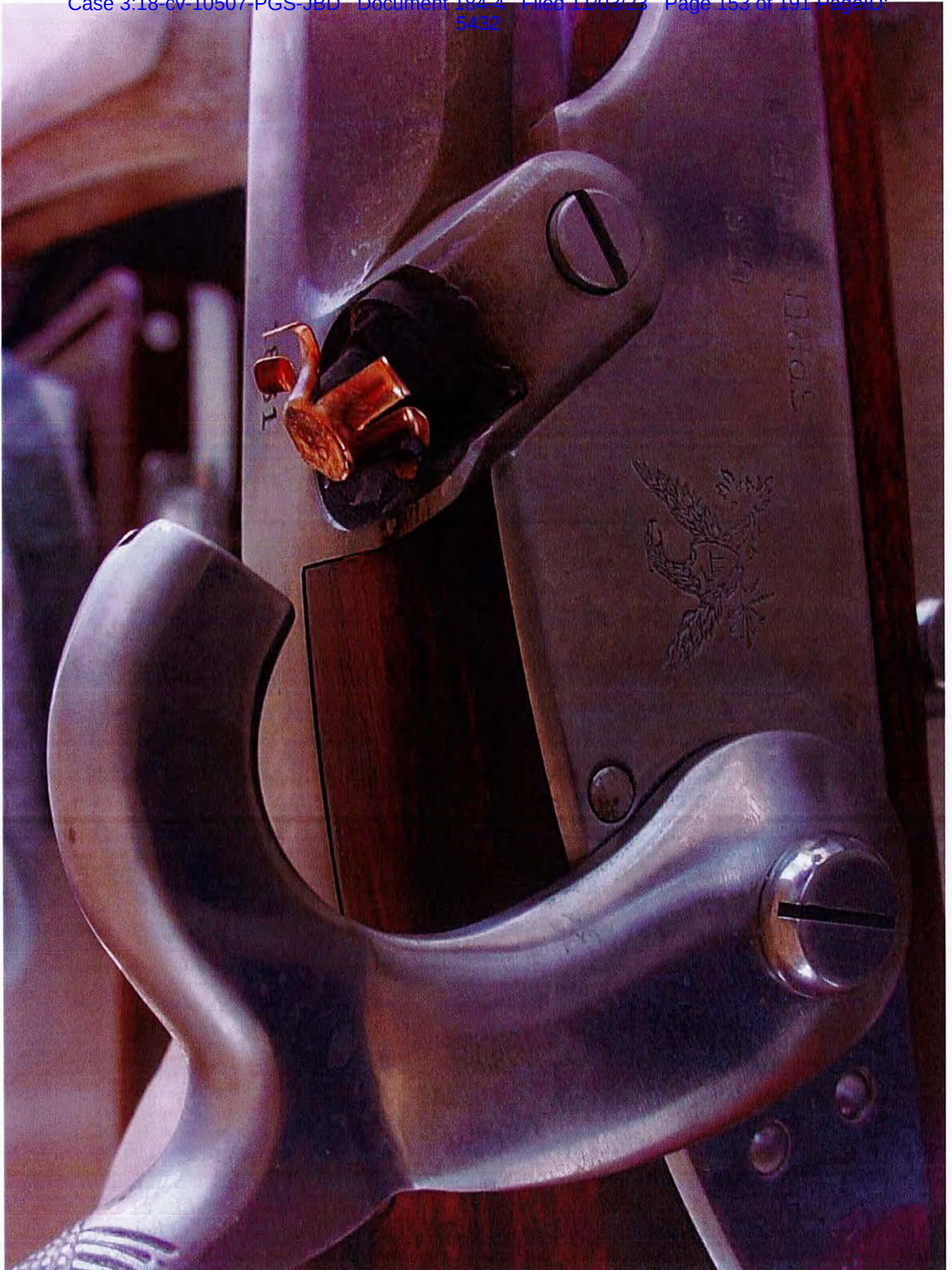
Academia.edu and Modern Heritage Foundation
websites.

Percussion Cap Ignition System

Courtesy Lucien Haag, FSSI







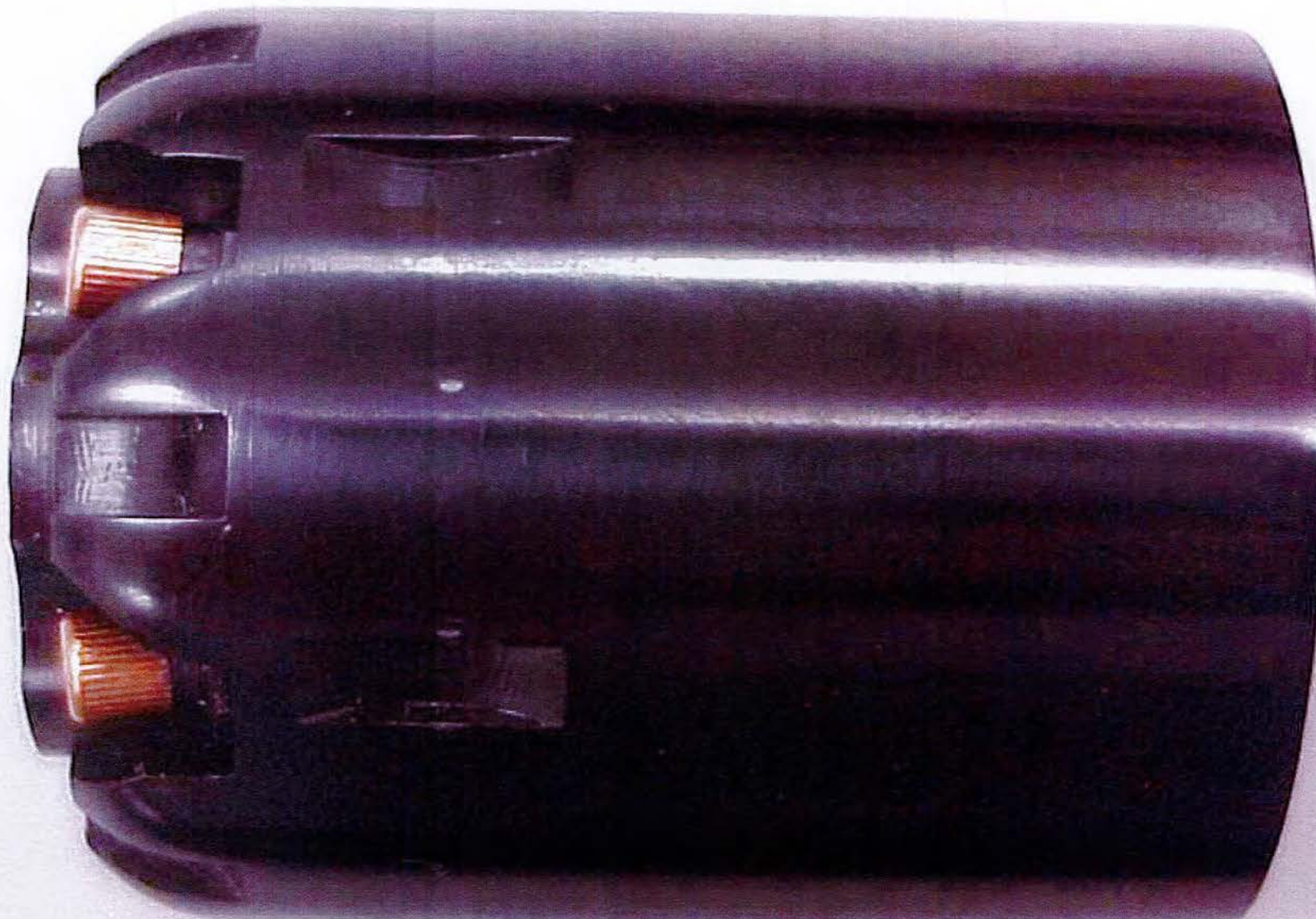


.44-Caliber Percussion Revolver

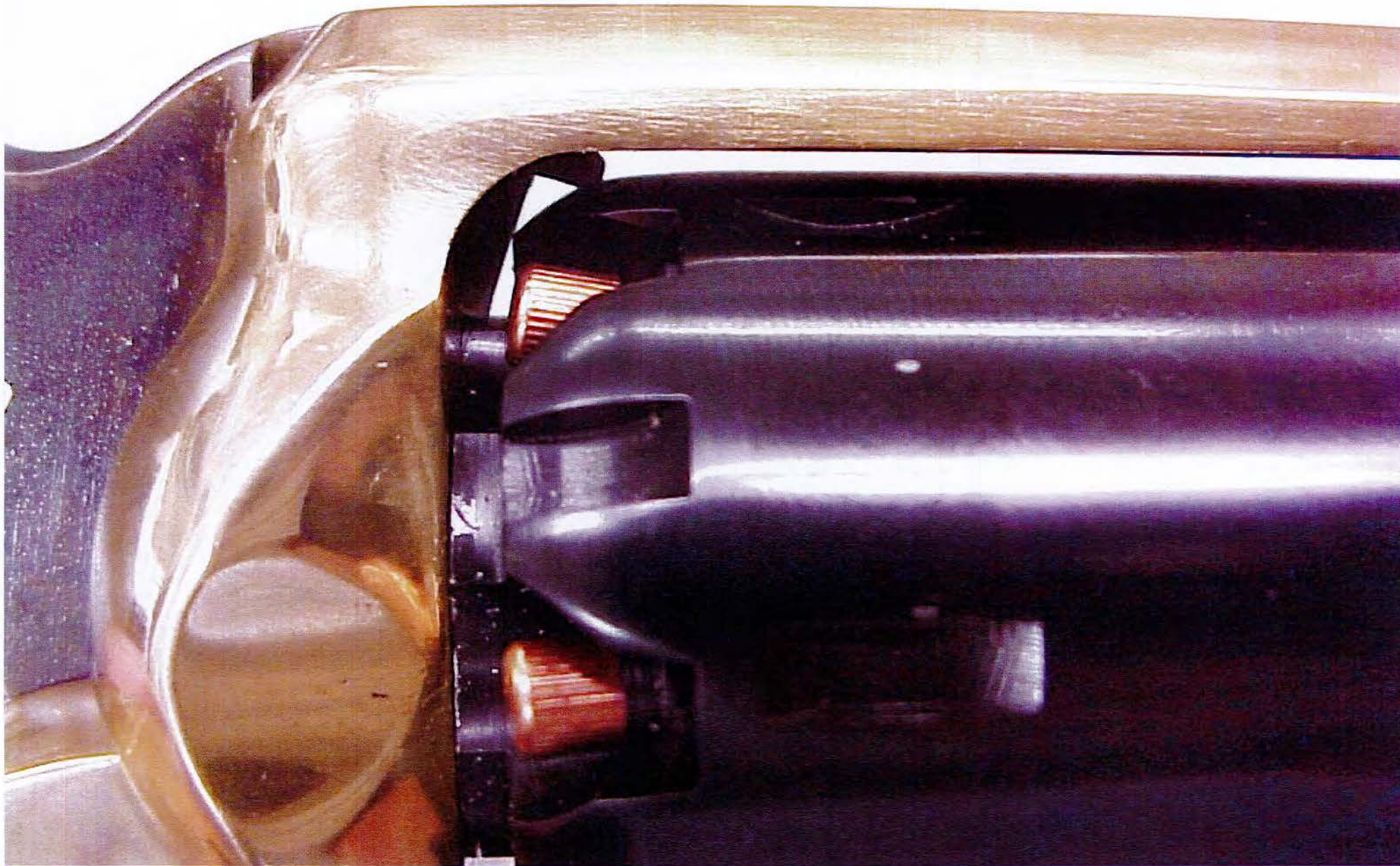


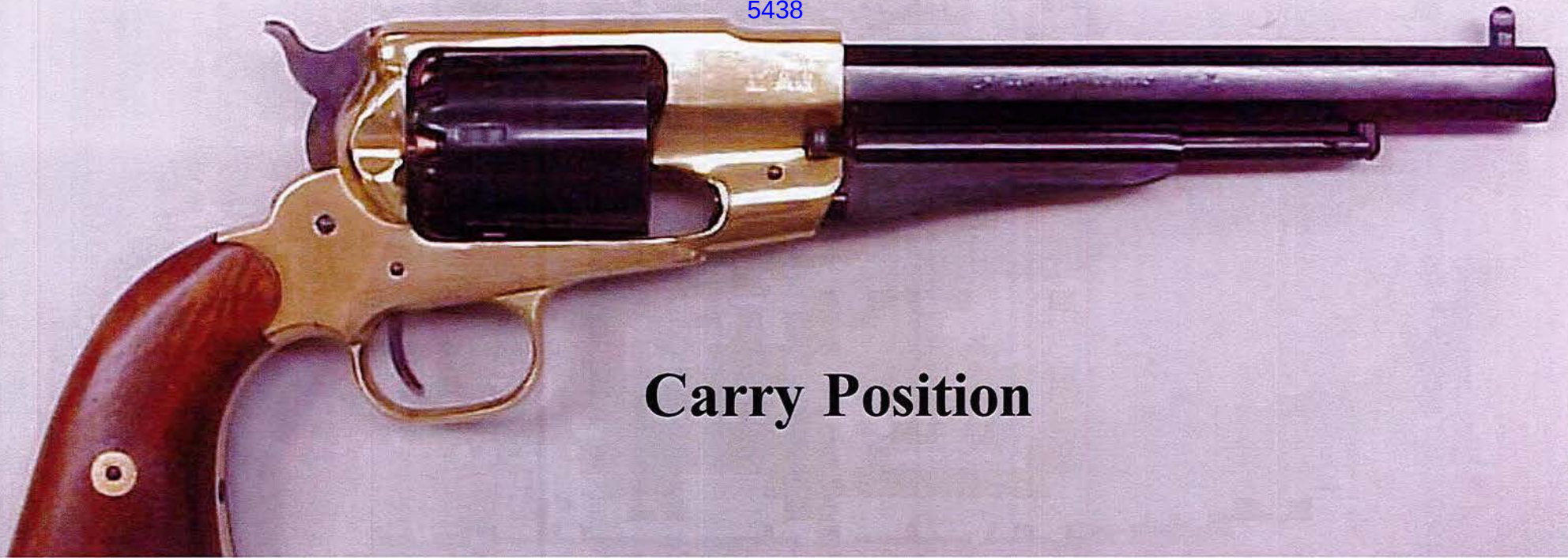


Cylinder with Percussion Caps on the Nipples



Hammer in Safety Notch (Remington Revolver)





Carry Position



Fire Position

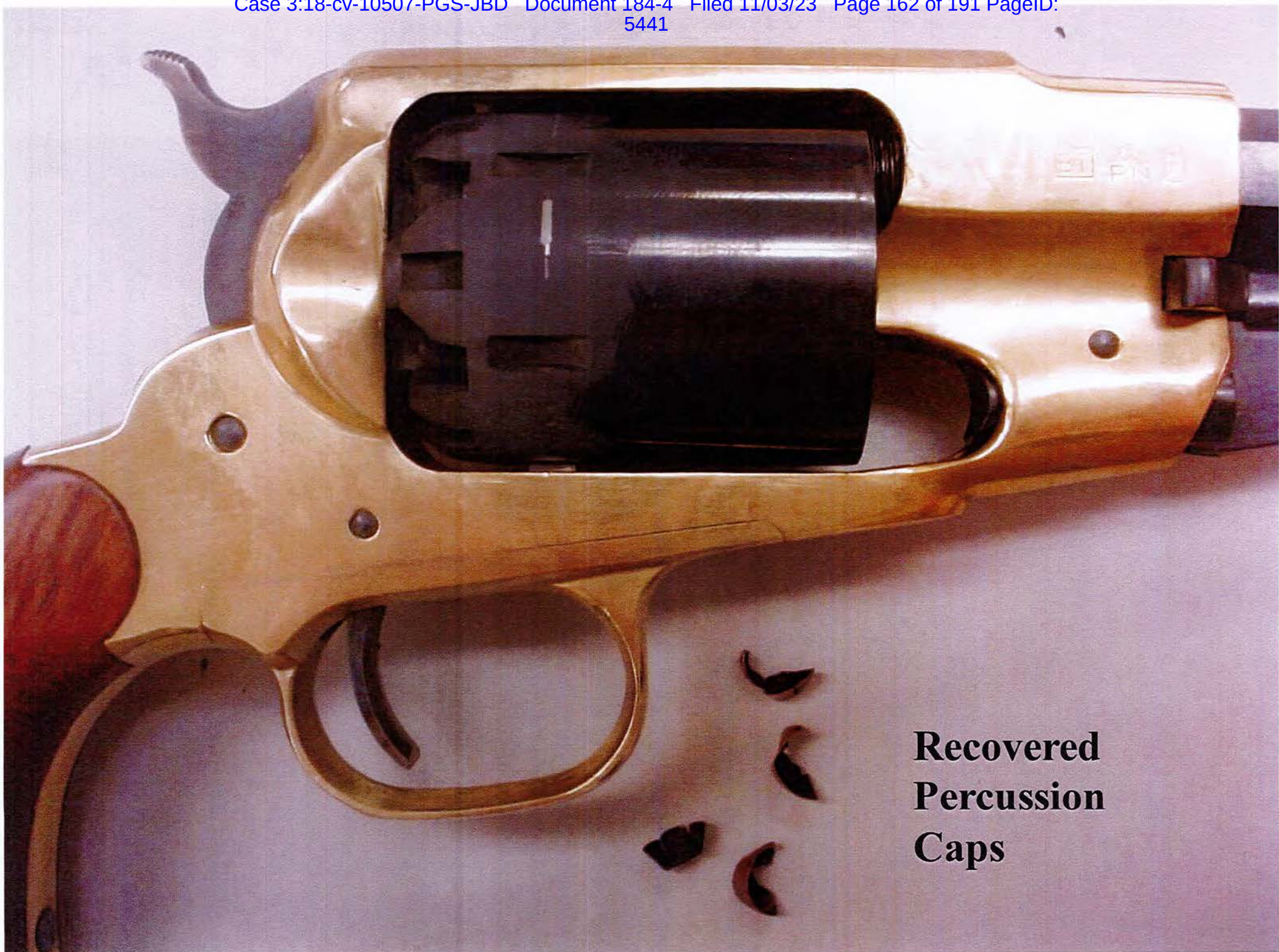


Hammer at

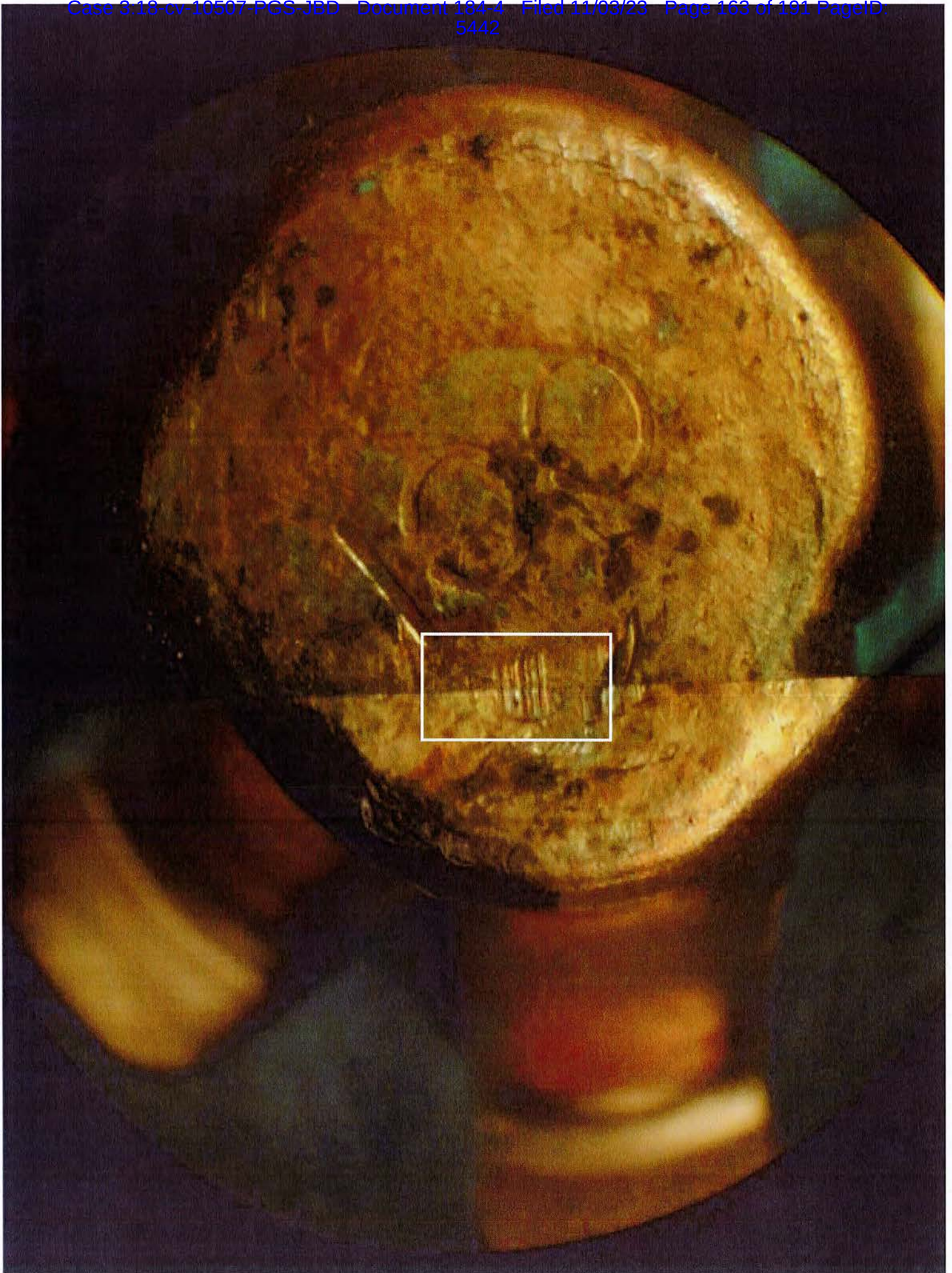
Full Cock

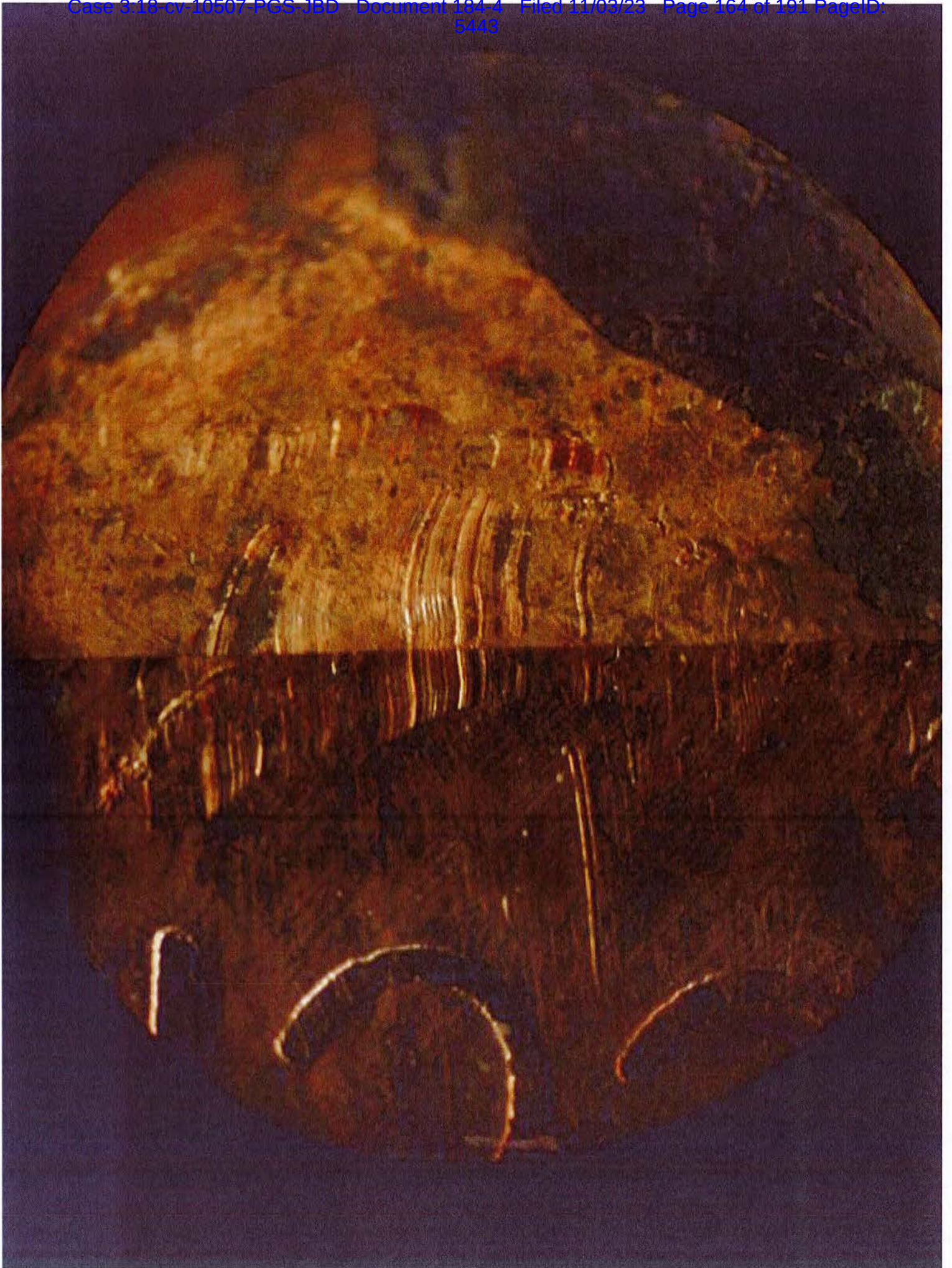
Fired Percussion Cap





**Recovered
Percussion
Caps**



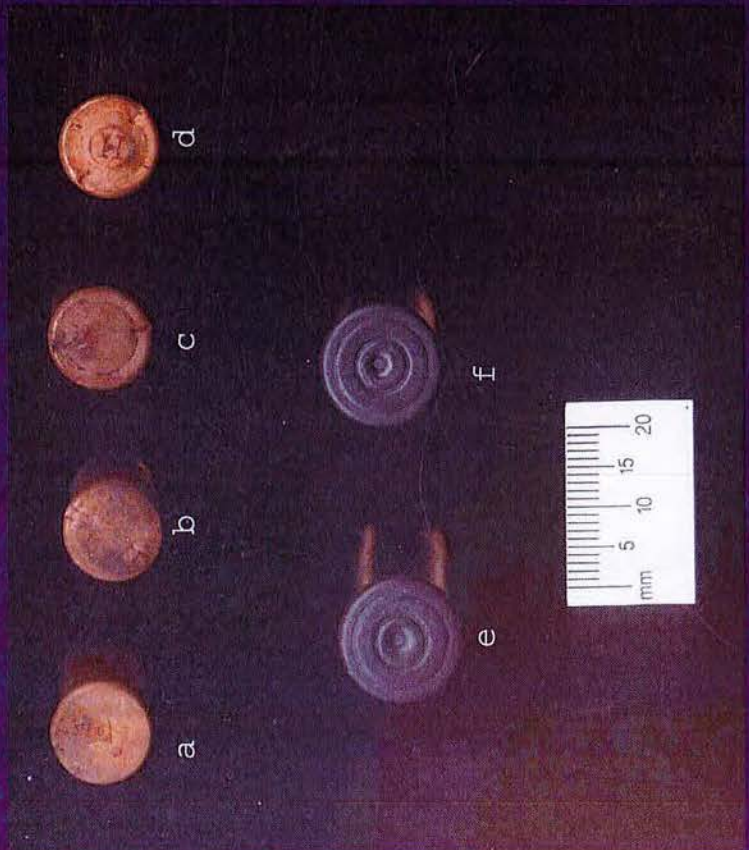
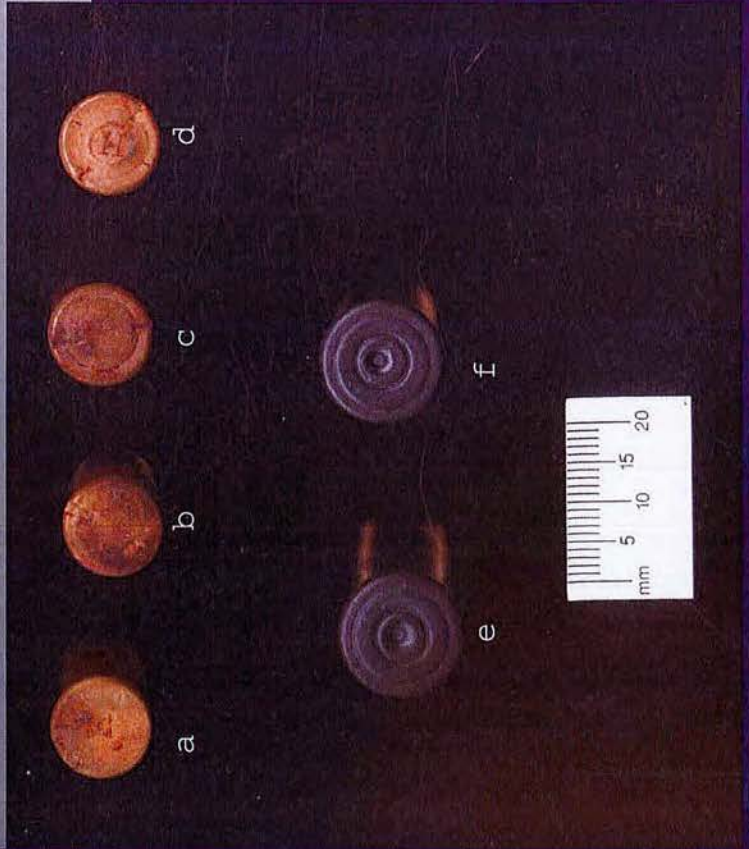


Percussion Cap and Blackpowder Firearm Analysis

References:

- Bishop, Eugene E.
1995 Toolmark Identification on a Black Powder Revolver. *Association of Firearm and Tool Mark Examiners Journal* 27(4):310-313.
- Cayton, John C.
1984 Blackpowder Firearms, Powder Residue, and Ball Penetration. *Association of Firearm and Tool Mark Examiners Journal* 16(4):80-81
- Haag, Lucien C.
2001 Black Powder Substitutes: Their Physical and Chemical Properties and Performance. *Association of Firearms and Toolmark Examiners Journal* 33(4):313-325.
- 2007 Matching Cast Bullets to the Mould that Made them and Comparison of Consecutively Manufactured Bullet Moulds. *Association of Firearm and Tool Mark Examiners Journal* 39(4):313-322.
- 2008 The Exterior and Wound Ballistic Aspects of Billy Dixon's Long Shot and the Battle of Adobe Walls. *Association of Firearm and Tool Mark Examiners Journal* 40(2):195-213.
- Weber, Kent P. and Douglas D. Scott
2005 Applying Firearm Identification Procedures in the Analysis of Percussion Caps. *Association of Firearm and Tool Mark Examiners Journal* 37(1):34-44.
- Weber, Kent P., and Douglas D. Scott
2006 Uncapped Potential: Applying Firearms Identification Procedures in the Analysis of Percussion Caps. *Historical Archaeology* 40(3):131-143.

Metallic Cartridge Blackpowder Firearms





Rimfire Cartridges Used in Spencer Rifles and Carbines

**.38
LONG**



.38 long

The cartridge used in Spencer's earliest, prototype, small-frame sporting rifles. Originally known as the No. 38 cartridge.

**.44
LONG**



.44 long

Spencer's second prototype cartridge, used in his early, small-frame, military style carbines. Originally known as the No. 44 cartridge.

.56-.56



56-56 Spencer

The cartridge used in all Civil War Spencer rifles and carbines, including the Model 1860 Army and Navy rifles and the Model 1860 carbine. Originally known as the No. 56 Navy and Infantry cartridge.

.56-.50



56-50 Spencer

This cartridge was developed at Springfield Armory in late 1864, to be the standard ammunition for future carbines. It was originally known as the .50 caliber Springfield carbine cartridge.

.56-.52



56-52 Spencer

Developed commercially as an alternative to the 56-50 by Crittenden & Tibbals Manufacturing Company. It differed by its shorter case length, visible grease grooves, and more positive means of crimping the bullet.

.56-.46



56-46 Spencer

This cartridge was developed at Springfield Armory in late 1863, in an attempt to improve ballistics of the 56-56 Spencer by reducing the bullet diameter. It was one of the first bottleneck cartridges.

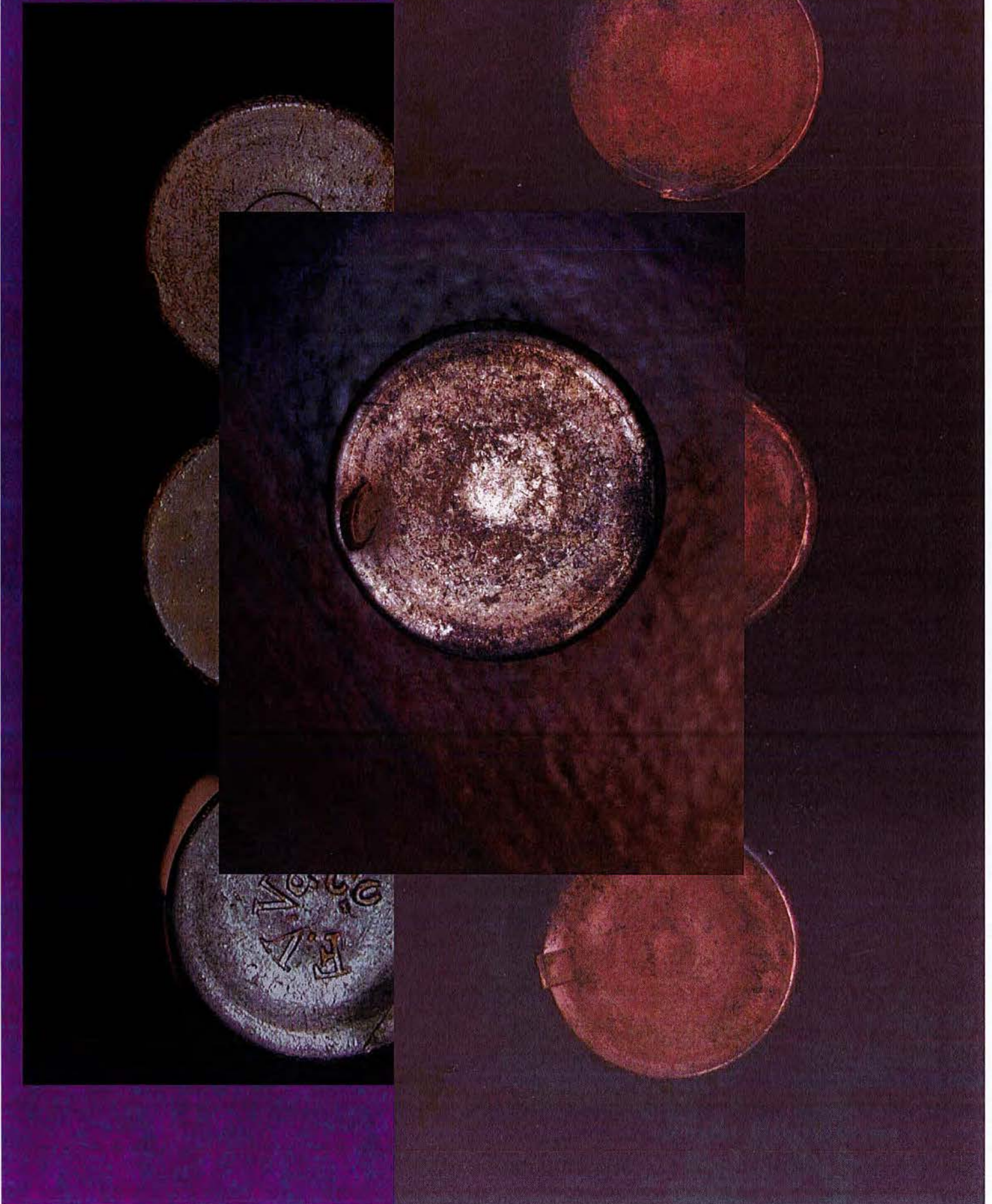
.56-.56 SPENCER CARTRIDGES

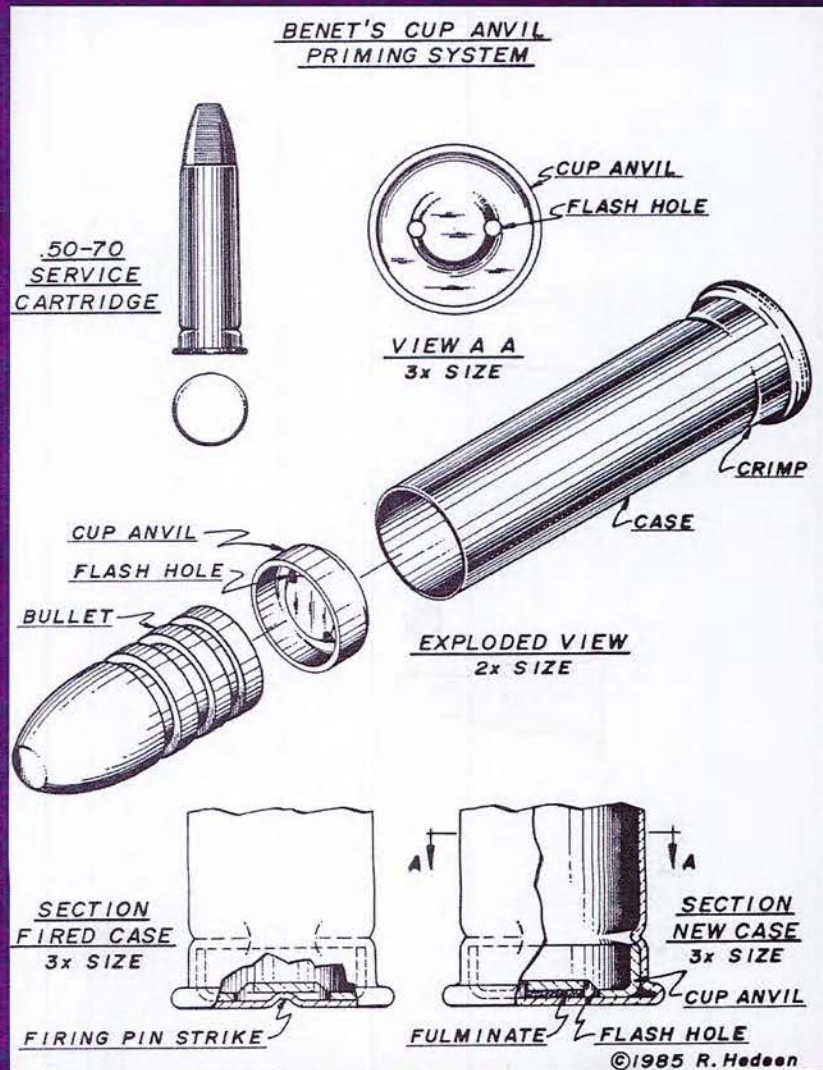
**420-gr.,
.550" dia.
bullet**

**549" dia. 548" dia. 541" dia.
bullet bullet bullet**



Slides and Images by Luke Haag – Forensic Science Services, Carefree, AZ
Spencer cartridges from the C. Vance Haynes collection – Tucson, AZ







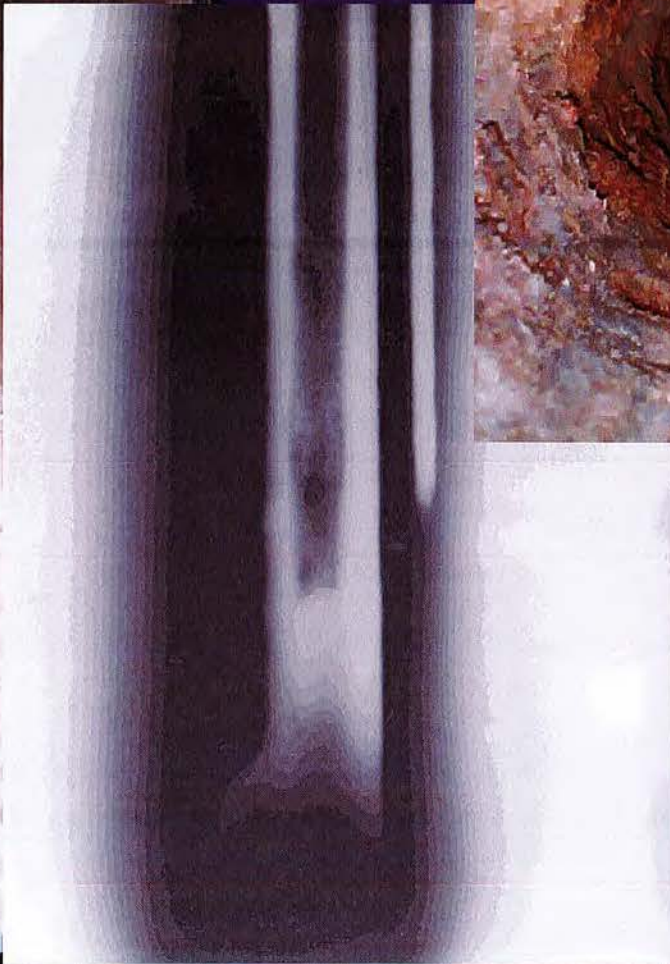
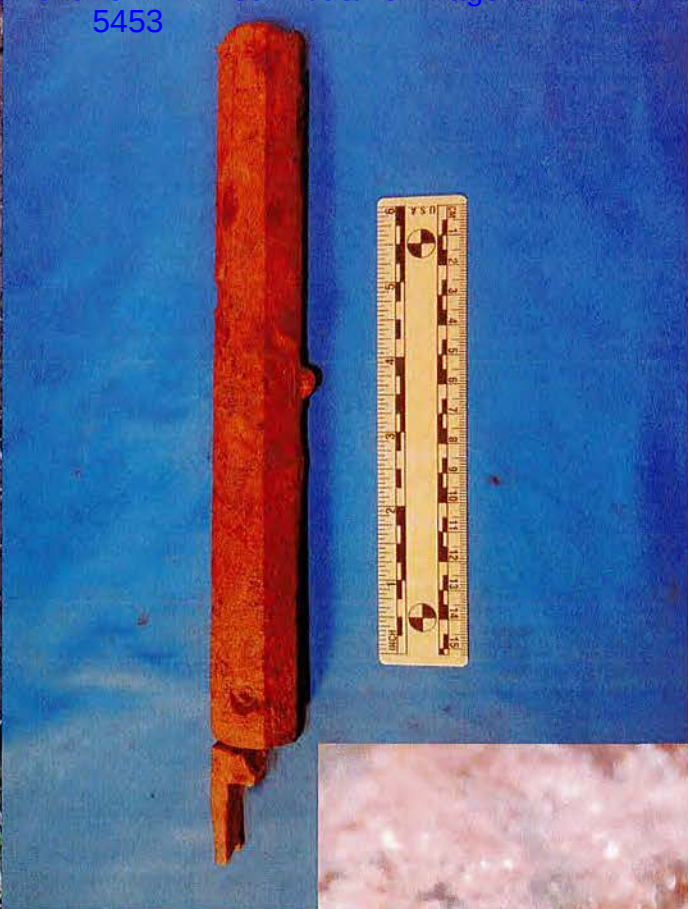




EXHIBIT 4

MARCH 7, 2015 TESTS
at
BEN AVERY RANGE

.72-Cal. "BROWN BESS"

Slides and Calculations

by

Luke Haag

Forensic Science Services, Inc.

Carefree, AZ

haagfssi@aol.com

BALLISTIC DATA

ROUND BALL DIAMETER: 0.718"

PROJECTILE WEIGHT: 552-gr.

POWDER BRAND: GOEX

POWDER TYPE: 2F

POWDER CHARGE: 100-gr. by volume

PATCH MATERIAL: cotton

PATCH THICKNESS: unk.

MET/SITE DATA

Temp. 70⁰F

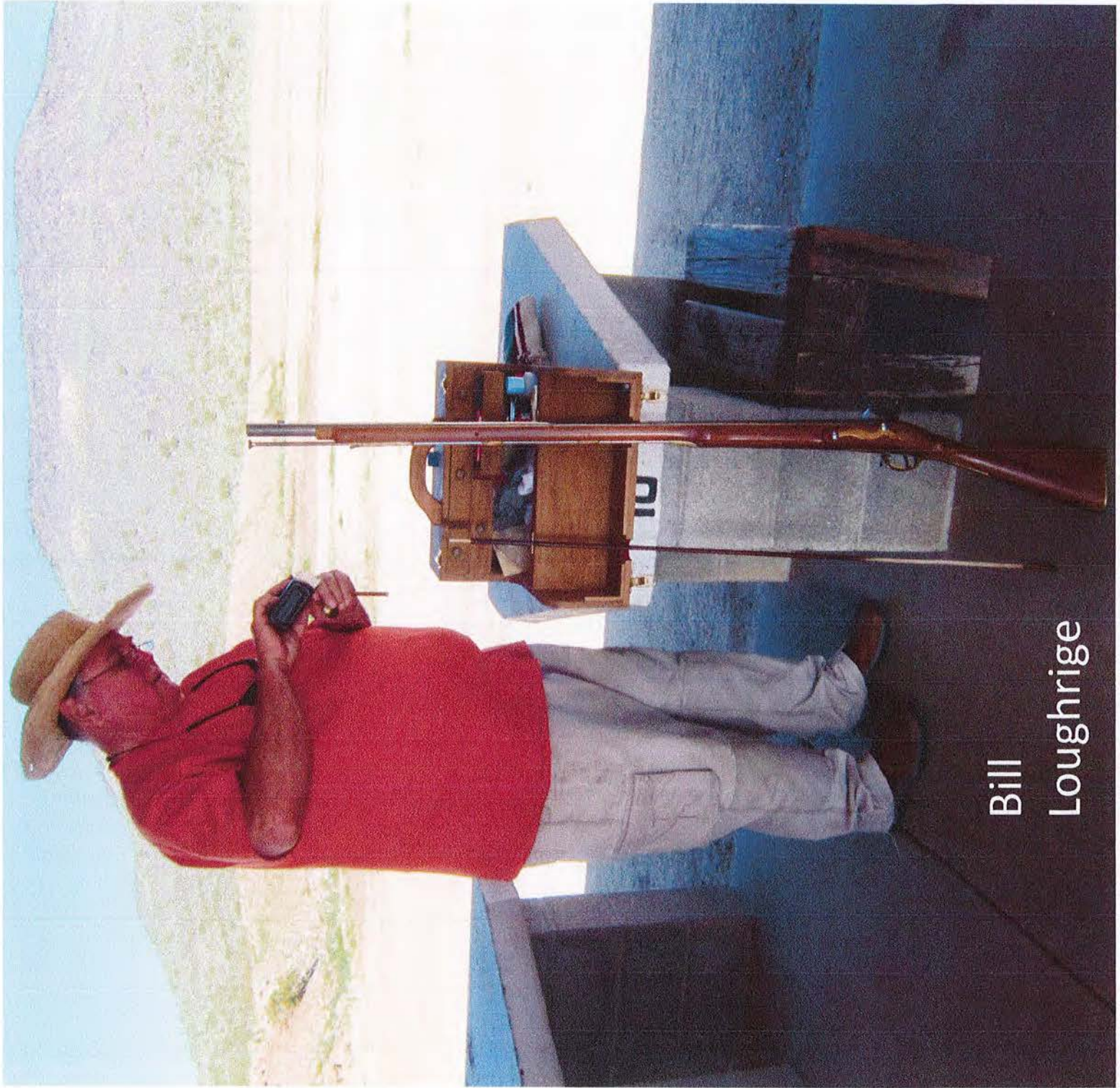
RH 15%

Baro. 29.89"Hg

Site 1632'MSL



Musket
provided by
Bill
Loughrige



Bill
Loughrige

PROJECTILES TRACKED
by
Luke Haag
with
FORENSIC SCIENCE SERVICES'S
INFINITION™ DOPPLER RADAR

0.718"

552-gr.

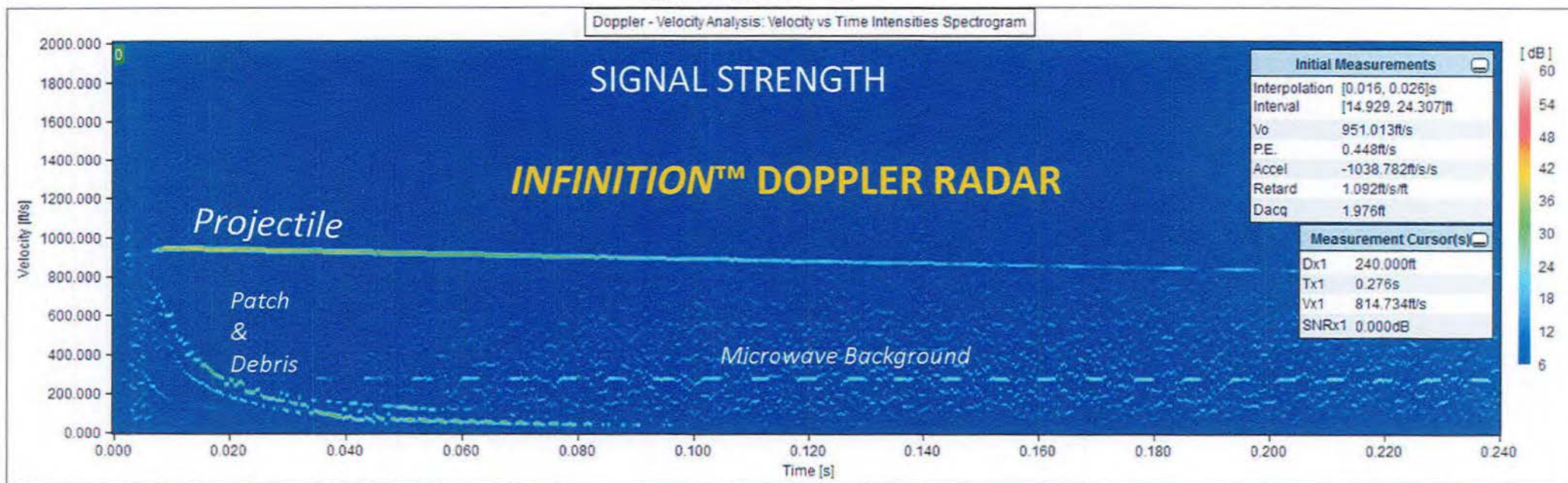
LEAD BALL



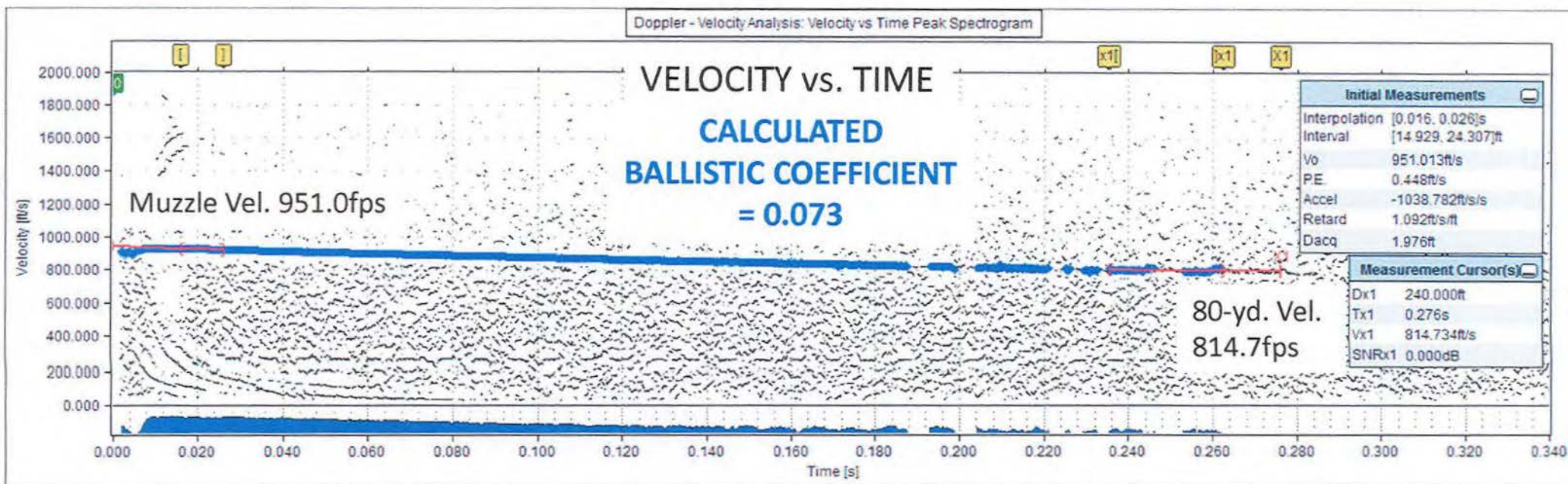
Lightning Powder Co., Inc.

(800) 852-0300

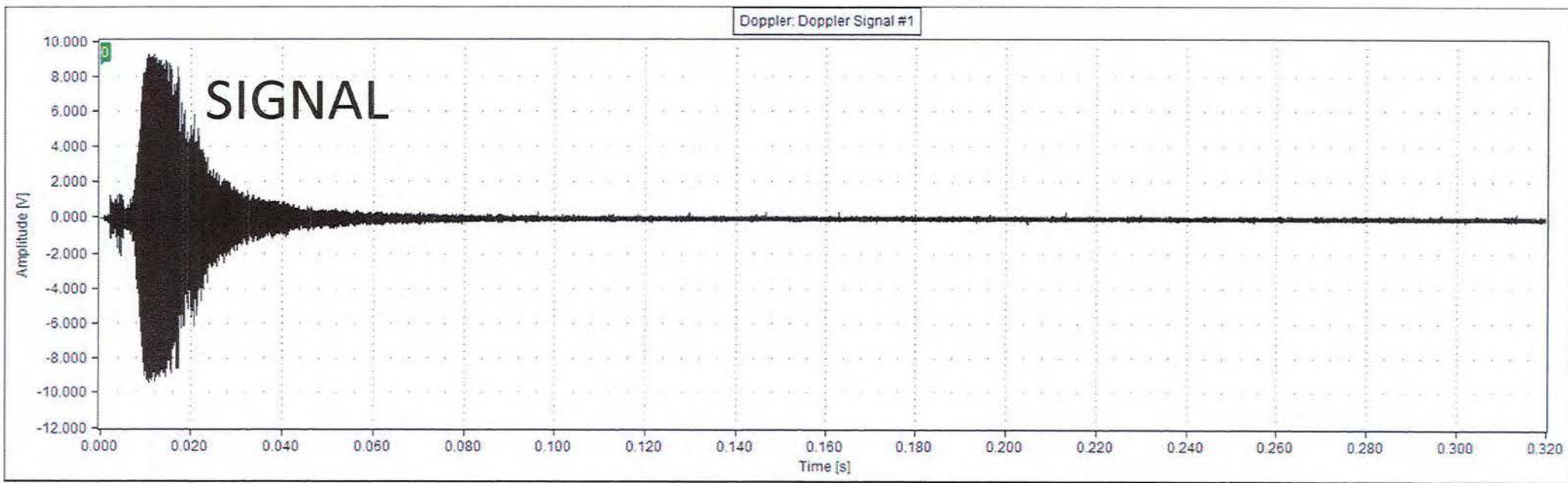
SHOT-1



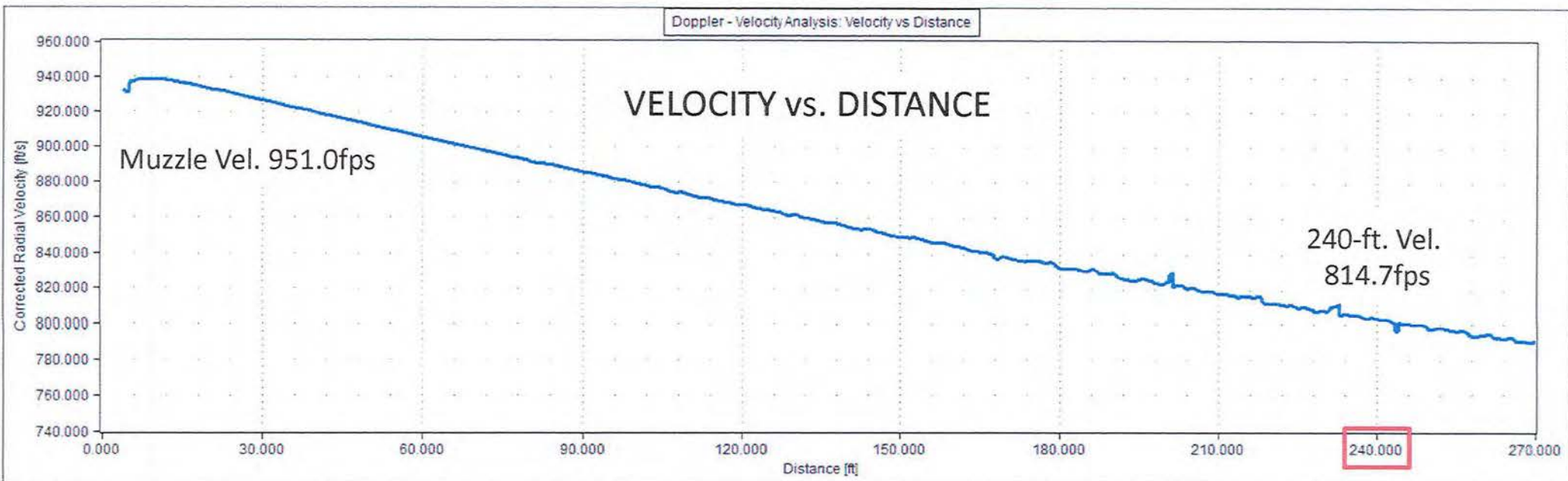
LOW VELOCITY SHOT



SHOT-1



LOW VELOCITY SHOT



SIERRA INFINITY-6 TABLE

Low Velocity Shot to 200-yards

Musket "Zeroed" at 50-yards

Trajectory for Custom .72 BROWN BESS at 951 Feet per Second

At an Elevation Angle of: 0 degrees

Ballistic Coefficients of: 0.073 0.073 0.073 0.073 0.073

Velocity Boundaries (Feet per Second) of: 1168 1168 1168 1168

Wind Direction is: 0.0 o'clock and a Wind Velocity of: 0.0 Miles per hour

Wind Components are (Miles per Hour): DownRange: 0.0 Cross Range: 0.0 Vertical: 0.0

The Firing Point speed of sound is: 1132.09 fps

The bullet drops below the speed of sound on the trajectory (1132.09 fps) at: 00 yards

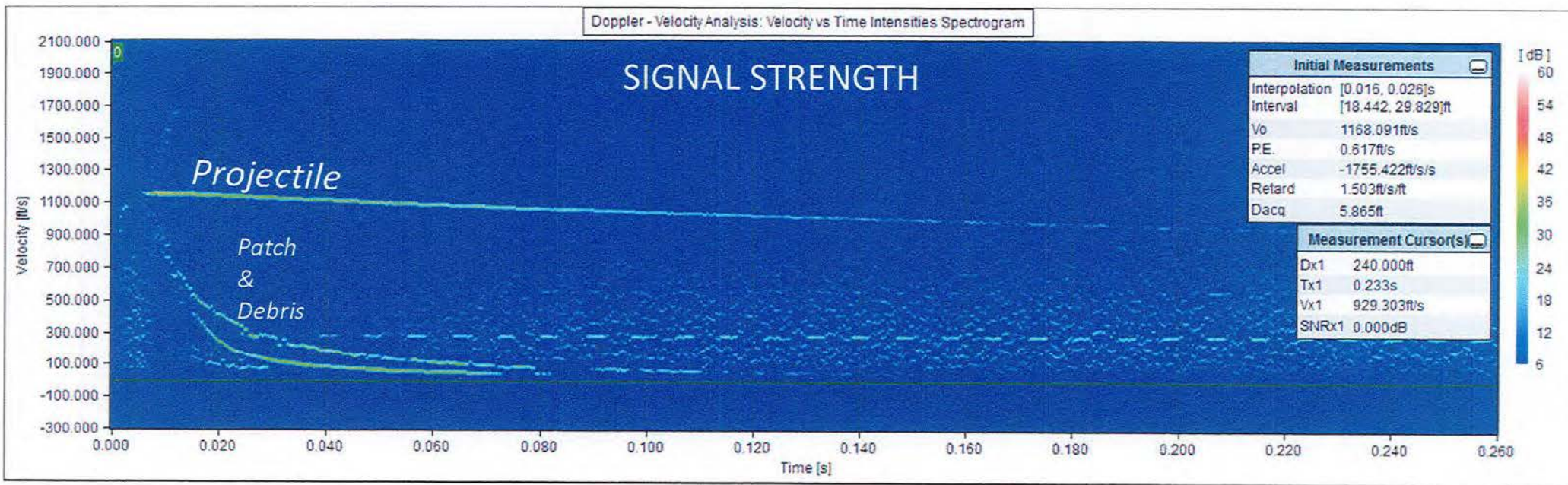
Altitude: 1632 Feet Humidity: 15 Percent Pressure: 29.85 in/Hg

Temperature: 70 F

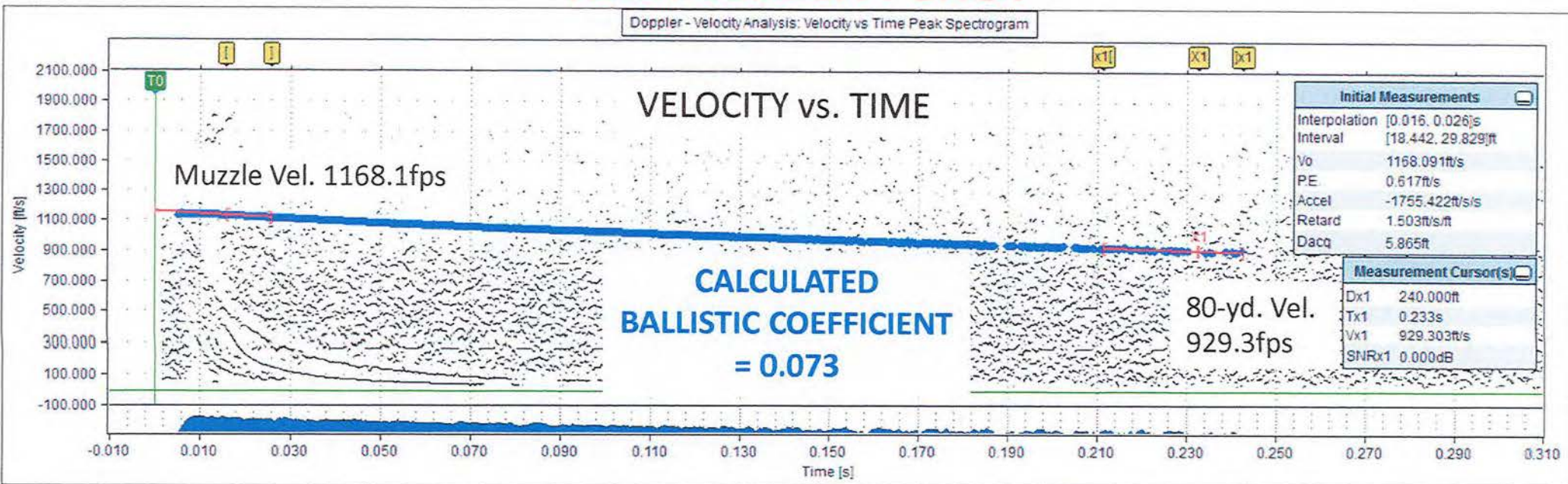
Data Printed in English Units

Range (Yards)	Velocity (Ft/Sec)	Energy (Ft/Lbs)	Momentum (Lb-sec)	Drop (inches)	Bullet Path (inches)	Bullet Path (1 MoA)	Wind Drift (inches)	Wind Drift (1 MoA)	Time of Flight (Seconds)
0	951.0	1108.3	2.33	0.0	-0.5	0.0	0.0	0.0	0.00000000
20	911.4	1018.0	2.23	-0.79	0.97	4.6	0.0	0.0	0.06447335
40	876.3	941.1	2.15	-3.26	0.77	1.8	0.0	0.0	0.13163025
60	844.5	873.9	2.07	-7.53	-1.24	-2.0	0.0	0.0	0.20139391
80	815.0	814.0	2.00	-13.75	-5.2	-6.2	0.0	0.0	0.27373159
100	787.3	759.7	1.93	-22.07	-11.25	-10.7	0.0	0.0	0.34864790
120	761.2	710.2	1.87	-32.63	-19.55	-15.6	0.0	0.0	0.42616586
140	736.5	664.7	1.81	-45.59	-30.25	-20.6	0.0	0.0	0.50631756
160	712.9	622.8	1.75	-61.11	-43.5	-26.0	0.0	0.0	0.58914867
180	690.2	583.8	1.69	-79.37	-59.5	-31.6	0.0	0.0	0.67471745
200	668.4	547.6	1.64	-100.55	-78.42	-37.4	0.0	0.0	0.76309385

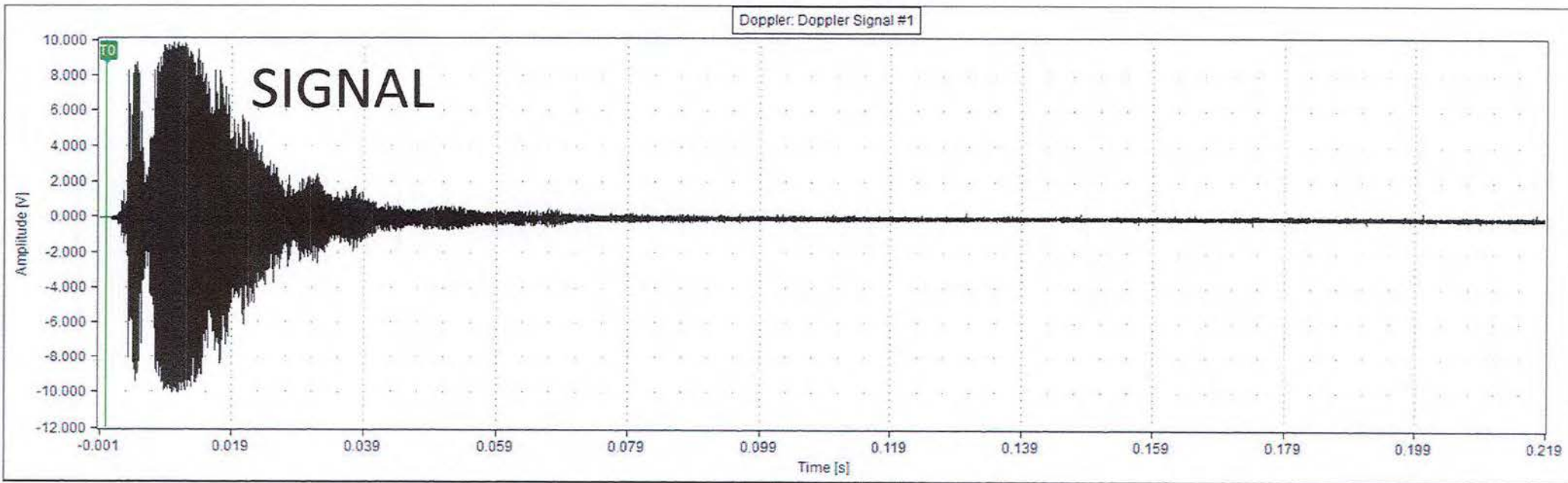
SHOT-2



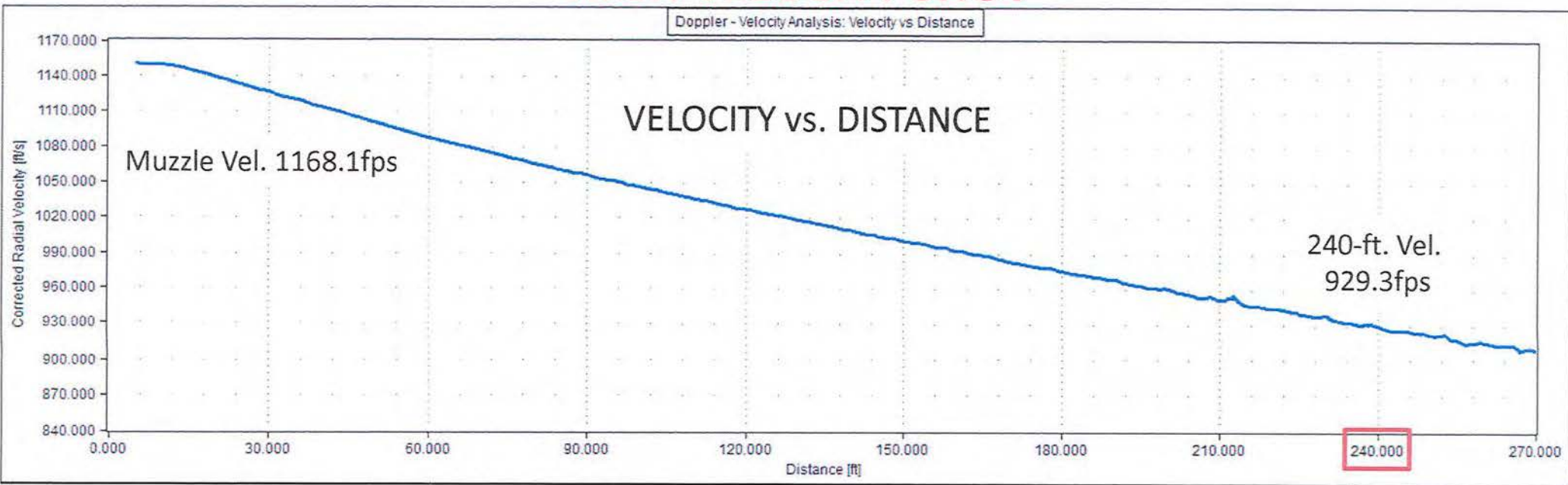
HIGH VELOCITY SHOT



SHOT-2



HIGH VELOCITY SHOT



SIERRA INFINITY-6 TABLE

High Velocity Shot to 200-yards

Musket "Zeroed" at 50-yards

Trajectory for Custom .72 BROWN BESS at 1168 Feet per Second

At an Elevation Angle of: 0 degrees

Ballistic Coefficients of: 0.073 0.073 0.073 0.073 0.073

Velocity Boundaries (Feet per Second) of: 1168 1168 1168 1168

Wind Direction is: 0.0 o'clock and a Wind Velocity of: 0.0 Miles per hour

Wind Components are (Miles per Hour): DownRange: 0.0 Cross Range: 0.0 Vertical: 0.0

The Firing Point speed of sound is: 1132.09 fps

The bullet drops below the speed of sound on the trajectory (1132.09 fps) at: 08 yards

Altitude: 1632 Feet Humidity: 15 Percent Pressure: 29.85 in/Hg

Temperature: 70 F

Data Printed in English Units

Range (Yards)	Velocity (Ft/Sec)	Energy (Ft/Lbs)	Momentum (Lb-sec)	Drop (inches)	Bullet Path (inches)	Bullet Path (1 MoA)	Wind Drift (inches)	Wind Drift (1 MoA)	Time of Flight (Seconds)
0	1168.0	1671.8	2.86	0.0	-0.5	0.0	0.0	0.0	0.00000000
20	1084.4	1441.0	2.66	-0.54	0.6	2.9	0.0	0.0	0.05340185
40	1021.6	1278.9	2.50	-2.25	0.53	1.3	0.0	0.0	0.11047282
60	971.3	1156.2	2.38	-5.3	-0.88	-1.4	0.0	0.0	0.17075016
80	929.0	1057.7	2.28	-9.82	-3.76	-4.5	0.0	0.0	0.23394502
100	892.0	975.2	2.19	-15.96	-8.25	-7.9	0.0	0.0	0.29987863
120	858.8	903.9	2.10	-23.83	-14.49	-11.5	0.0	0.0	0.36844878
140	828.4	840.9	2.03	-33.6	-22.61	-15.4	0.0	0.0	0.43960333
160	799.9	784.2	1.96	-45.39	-32.76	-19.5	0.0	0.0	0.51333091
180	773.1	732.5	1.89	-59.35	-45.08	-23.9	0.0	0.0	0.58964953
200	747.8	685.3	1.83	-75.64	-59.72	-28.5	0.0	0.0	0.66858605

EXHIBIT 5



Exhibit 5. Left to right: 12-gauge Winchester rifled slug cartridge; 12-ga. rifled slug showing hollow base; 12-ga. rifled slug side view; .69 caliber Brown Bess musket ball.

EXHIBIT 6

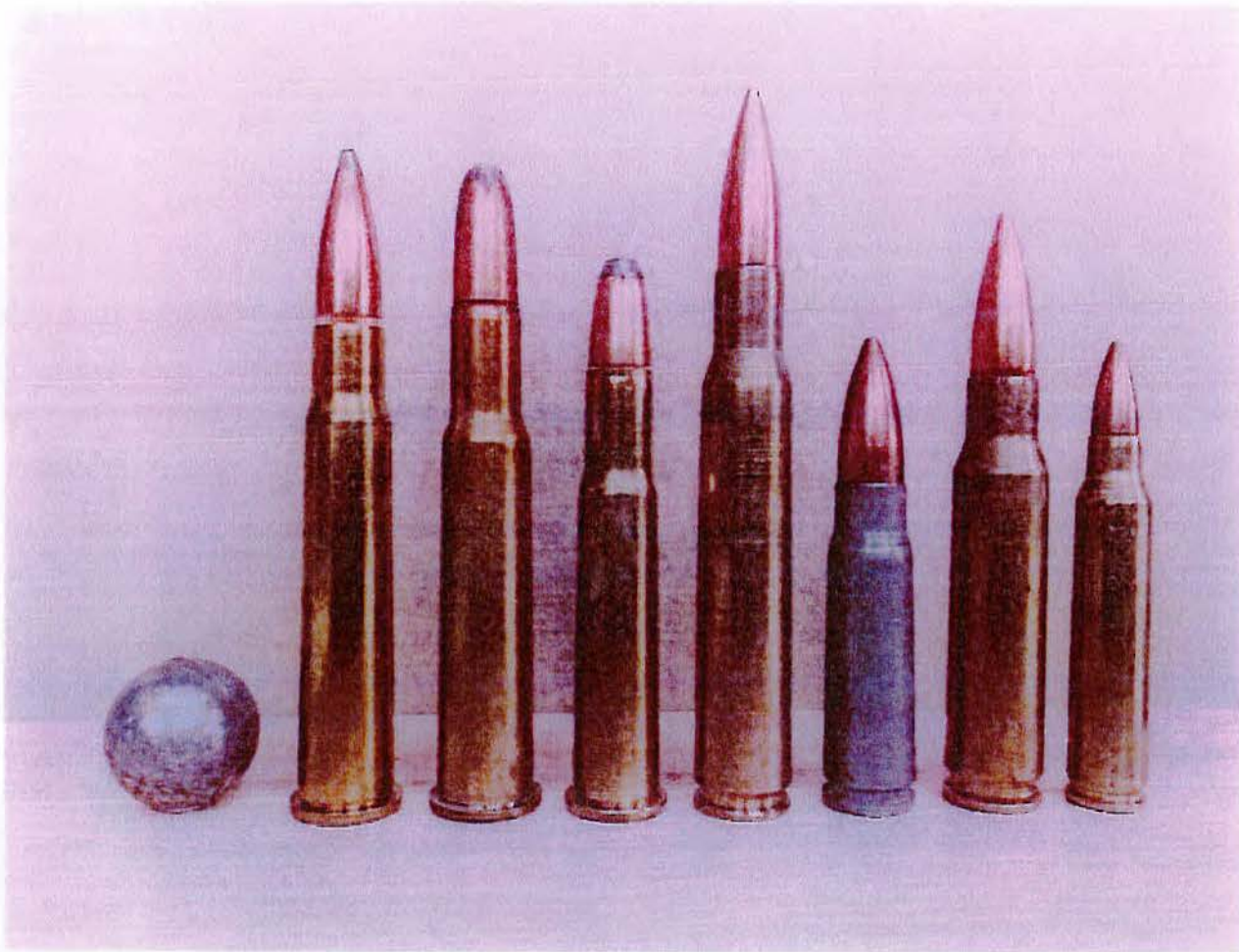


Exhibit 6. Left to right. .69 caliber Brown Bess musket ball (1722-1867); .303 British cartridge (1888); .30-40 Krag (1892); .30-30 Winchester (1895); .30-06 (1906); 7.62x39mm AK-47 cartridge (1947); 7.62mm NATO/.308 Winchester (1950's); .223 Remington/5.56mm NATO AR-15 cartridge (1960's-1970's).